STRONOMY
OBSERVATION.

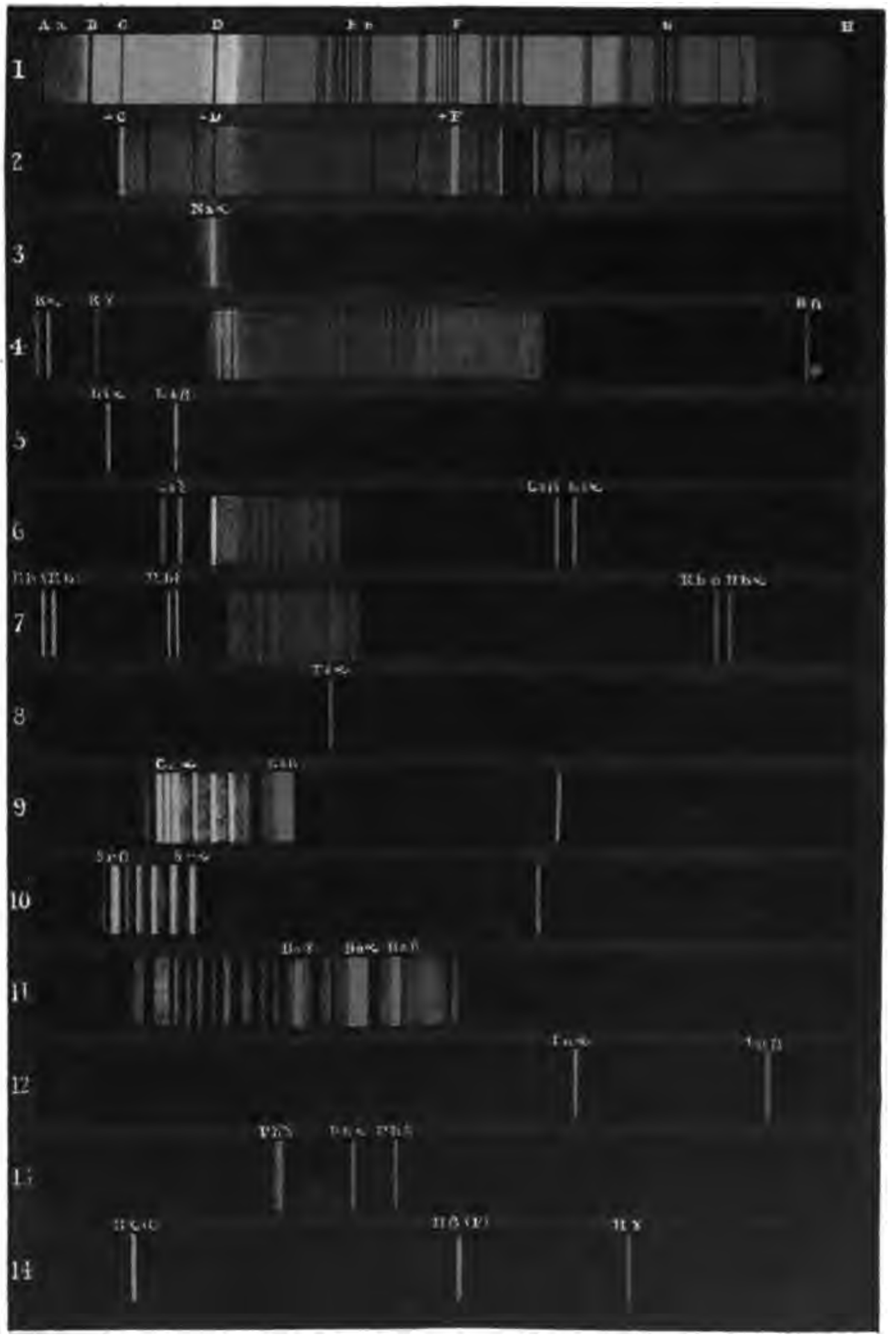
BY

ELIZA A. BOWEN

D. APPLETON & CO. NEW YORK.

ASTRONOMY BY OBSERVATION.

PECTRA OF VARIOUS SOURCES OF LIGHT.



1. *The Sun.* 2. *The Sun's edge.* 3. *Sodium.* 4. *Potassium.* 5. *Lithium.* 6. *Caesium.* 7. *Rubidium.* 8 *Thallium.*
9. *Calcium.* 10. *Strontium.* 11. *Barium.* 12. *Indium.* 13. *Phosphorus.* 14. *Hydrogen.*

NEW YORK: D. APPLETON & CO.

ASTRONOMY

BY OBSERVATION

AN ELEMENTARY TEXT-BOOK
FOR HIGH-SCHOOLS AND ACADEMIES

BY

ELIZA A. BOWEN

NEW YORK
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1886

Brasch

TO

MRS. ZOE DANA UNDERHILL,

WHOSE ENLIGHTENED APPRECIATION OF OBSERVATION-STUDY

STIRRED ME UP TO WRITE THIS BOOK,

AND WHOSE STEADY FRIENDLY ENCOURAGEMENT

SUSTAINED ME THROUGH SEVERAL YEARS OF EXPERIMENTAL WORK.

PREFACE.

THIS book has grown out of actual school-work, in which it was the teacher's object to make pupils studying elementary astronomy *observe* and *think*.

The following are its chief peculiarities:

1. An efficient, easy, well-tried plan for teaching the constellations is described. Its use will obviate the necessity of a teacher doing work out of school-hours, by enabling students to become independent observers.

2. Careful directions are given when, how, and where to find the heavenly bodies. Their motions are described in the order in which they can be seen by an observer, and in familiar language. Thus, the text-book may be a guide to the observation of beginners.

3. The student is excited to thought. Facts are stated first; theory afterward, as a deduction from the facts. The selection of subjects for the student's thinking is a little different from that of other school astronomies. The general principle governing this selection is to make the student understand *what he can see*. The author has also desired in some degree to separate the work of the elementary teacher from that of the college professor. To observe the facts from which Copernicus argued; to discuss them; to perceive how they prove his conclusions; to use in this the simpler geometrical conceptions, seem to the author suitable elementary work. It would be excellent elementary work if it could be combined with some practical angular measurements of a simple kind on the heavens.

Practically, neither the college professor nor the elementary teacher can draw a clear line separating their work. It would be very unfortunate if these few words suggest, for judging of the author's humble book, a severe abstract rule, which the practical condition of the schools makes it impossible for any elementary teacher to observe.

The author knows high-school work well. The *thinking* of this book is fairly within the comprehension of the students of our reasonably good schools. The professed study of the theory of astronomy, in which there is no thinking, is a counterfeit.

The book presumes in those who study it a little knowledge of elementary geometry, and of the refraction, reflection, and dispersion of light. As all high-schools teach as much of these subjects as is needed, it seemed better to take thus much knowledge for granted, than to make a digression for the purpose of presenting it.

The author has probably experimented as much as anybody in teaching elementary pupils by observation and by questions which drew them out to discuss theory. But much review is always required, and, in order to save time, a text-book is necessary for it. Also, we can not ring up the planets, like scenes in a theatre, to be studied during the school-session, and therefore the theory must sometimes be taught in advance of actual observation. The author hopes the book will be useful for these purposes to teachers who use improved methods.

In writing it, another class of teachers has been much in view. In our high-schools and academies the teaching of astronomy is often in the hands of instructors who have little or no practical knowledge of the science. They are usually intelligent persons who would improve if the text-book were a guide to observation.

Another class of persons has also been in view. Of late years a great spirit of study has arisen among young people out of school. Their situation is very favorable for the study of astronomy, since they are not bound by school hours and sessions, but can take the planets when they come. It is hoped that they will be encouraged to study the heavens if a sufficient guide to observation is furnished. No study lends itself better to teaching by correspondence than astronomy.

BEECHCROFT SCHOOL, TENN., *Dec.* 20, 1885.

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INTRODUCTION.

For Teachers and Private Learners.

HOW TO LEARN AND TEACH THE CONSTELLATIONS.

We can not help seeing the motions of the heavenly bodies, unless, like Bunyan's man with the muck-rake, we steadily look down. A professed study of astronomy which does not make us recognize these bodies and their motions, when we see them, may not be useless, but it bears some marks of counterfeit knowledge. A mere acquaintance with the constellations is a very subordinate part of the knowledge here recommended, but it has, besides its own value, a good deal of importance as a prerequisite to the rest.

There are two disadvantages in the way of a teacher who wishes to make his pupils in astronomy really study nature. He can not be with them at night without inconvenience, and work outside of school-hours. This is the first difficulty. Another is, the impossibility of having the planets brought out for inspection when we want them, and also because, when they come, their motions are very slow.

After struggling a good deal with these disadvantages just mentioned, I found that by making young students learn the heavens as they do the maps of the United States or Europe, viz., by map-drawing, the whole of the first difficulty was obviated, and a large part of the second. They found the star-groups without trouble, for themselves. They were trained in observation, and they learned a great many of the motions incidentally. They became independent observers, and were so much interested in the practical study, that there was no doubt they would see and study for themselves whatever they could not see during the school-session.

No doubt a great many teachers can carry on this work quite as well as I can, or better; but, for the benefit of those who can not, I will describe it somewhat in detail.

The brighter stars in all the constellations, when joined by imaginary lines, form figures which are very easily recognized when once suggested. They are thus drawn in dotted lines on the maps attached to this book. If the student takes one figure at a time, and draws it repeatedly, until he gains the power to reproduce it on paper from memory, rapidly, without erasures, and with a fair degree of rough correctness, he can easily find it for himself if it is a conspicuous constellation, and he has some general idea in what part of the sky to look for it. And even if it is not a conspicuous constellation, he can easily find it, if it is adjacent to a constellation already known, and in a known direction from it. Thus, beginning with conspicuous constellations, and proceeding to adjacent ones, and then to others adjacent to the last, they are all easily learned.

But this plan of teaching by map-drawing is not a mere substitute for what is called "pointing out the constellations," and is not adopted and recommended only because the other course is inconvenient or impossible when teacher and class lodge in different houses. It is so much the easiest way, that when instructor and pupils are already together in the evening, and the latter wish to learn the star-groups, the teacher will do well to sit in the house (as I have often done), draw the figures on paper or a blackboard, and send students out to look for them. At first they feel helpless, and object; but a little trial soon convinces them how easy it is. If any find a difficulty, the others help them; and thus a teacher is spared additional work.

But mere drawing by the teacher is not sufficient, nor is that the plan recommended here. By the method described in the two preceding paragraphs, it is easy to have star-groups recognized at the time, but they will not be remembered, and must be taught again. Drawing by the pupil not only makes it easier to find them; they can hardly be fixed permanently in knowledge during the school-study, except by repeated drawing from memory. Whenever students have a few leisure moments, they should be called upon to cover the blackboard with these figures, or to reproduce them rapidly upon paper.

In order to secure repeated observation, it is best to have the groups learned one at a time; for, whenever the student goes out to find a new group, he is sure to look again at the old ones. The groups are both fixed in memory, and the habit of observation is strengthened. But the study of the motions gives far more interesting work than the mere identification of star-groups.

Any method of map-drawing already used in a school will answer for this purpose when carried out under the restrictions to be hereafter mentioned. The plan which I practice and recommend is called "drawing by dictation," now much practiced in the best schools. The teacher leads, standing at the blackboard, while pupils draw at desks in unruled exercise-books, which should not be used for any other purpose. When a teacher is wholly incapable of drawing even these simple figures, he can select some pupil to take the lead, who learns be-

forehand how to draw this group. Sufficient command over a pencil for this purpose is very common in all schools. Of course, the teacher is present to direct. The leader at the blackboard draws one of the lines of the figure and pauses a moment, while pupils follow with pencil and paper. Then he draws another line, and they follow, and so on until all the lines are finished. These lines are dotted on the map, but, in the exercise described, they are drawn continuous but very lightly. As the leader draws, he calls attention to the dimensions and positions of lines. No erasure whatever should be allowed. This is an important direction, for, unless it is observed, the teacher will be discouraged by the time consumed. It is not necessary to have more than a rough correctness, though, of course, pupils must not be encouraged to draw carelessly. After the lines are drawn, they must make the stars, the leader calling attention to the number and position. In the drawings made by leader and pupils, stars of the first magnitude are best represented by the symbol **O**; of the second, by ∗; of the third, by ×; of the fourth, by . In the "Description of Constellations," in the Appendix, there is given the number of first and second magnitude stars for each figure, and other information of value in studying them. After each constellation is drawn, the name should be written two or three times, and also the names of any first and second magnitude stars mentioned in the "Description." Then students should be called upon to repeat names aloud, separately and in unison. Without this exercise, they struggle a good deal with the names.

The drawing of a constellation must be made two or three times rapidly, and then the students are directed to turn over a leaf and draw from memory. The whole exercise, properly managed, need not take more than ten minutes. It should take place on the morning of a day which looks as if it would be followed by a clear night. If rain and interruption occur, the exercise should be repeated when again there seems a chance for observation at night. Each repetition takes less time. After drawing a figure, the student is always told to turn it in every direction, and is warned that he can not be sure beforehand exactly how it will be turned.

There is one important warning in regard to students who have identified one constellation and are beginning to learn an adjacent one. If a teacher, trying this method, fails in making his students learn the constellations, it will probably be from carelessness about this matter now to be explained. A picture of a constellation looked down upon, so reverses the directions of the same figure looked up to on the heavens, that the student who remembers the picture finds himself, as he says, "turned round" when he looks up. If he is merely studying a single figure, occupying a very small portion of the heavens, he can in a few moments recover his bearings, and recognize the group sought.

But, when the study by picture comes to be applied to a larger portion of the heavens, or more than a single figure, unless the student has the additional aid now to be explained, he will get not only "turned round," but seriously confused and perhaps discouraged as to his power to find anything at all without some one at his elbow. After learning to draw a group from memory, the student must make sure of the direction in which it lies from the known group. It should be the teacher's business to drill him on the direction of the new group from the known one. He should point out the side of the old one on which it is to be found, and he may draw the two together.

After he has made the drawing, and knows the direction of the new group from the old one, he should proceed rigorously in the following order when he studies the heavens: 1. He finds the known constellation. 2. Dismissing from his imagination all remembrance of figures, he finds carefully the proper direction from the known group. When he is sure of the direction, and not until then, he recalls the new figure which he has drawn, and he usually finds it in a few minutes.

The student should be well drilled in this order of proceeding, made to repeat and understand it.

The student should not *begin* by studying the maps of the book. He will think they are intended to aid him in finding the direction of groups *from himself* and the horizon. They do, it is true, show him the general aspect of the heavens at the times indicated on them. This is the aspect of the circles at the time of the equinoxes and solstices; and one object of the maps is, that the student may, after learning star-groups separately, know these. It is also the object of the maps to show the figures of the constellations and their directions from each other, and also the position of the various groups in regard to the ecliptic, the equinoctial, and colures, but not in regard to the observer and horizon.

When the first constellation is learned, the teacher (who looks it out beforehand) tells pupils where to look for it; and, whenever a constellation is studied, not adjacent to known ones, this must be repeated. But, after they learn a few, students cease to think of the position in regard to the inclosing horizon, and see that the maps can be used to learn new constellations adjacent to old ones. They then disregard the relation to the horizon, and often extend their knowledge in advance of the drawing. But the teacher should not stop the drawing. The securities for permanent and accurate knowledge are very insufficient without it.

The direction of star-groups from the observer and his horizon could not be permanently given by maps, for these directions are all the time changing. It is true, a globe can give them so that the change will not be noticed for a little while. But the globe can not be made a satisfactory help in studying the star-groups unless we use the directions from adjacent groups as well as directions from the horizon.

The dictation exercise in drawing, which has been recommended and described, is a species of free-hand drawing, which affords valuable training to hand and eye. Students can certainly learn the figures by drawing directly from the maps, but they will make little cramped figures, and find it difficult to draw any others, even on the blackboard.

I will state that, in using this book, I should have pupils study Chapter I, and then devote two weeks to study of con-

stellations by map-drawing, before beginning Chapter II.* It is not easy to have good book-study done concurrently with drawing and identifying star-groups. The knowledge of the constellations is of indispensable importance in studying the motions of the solar system in nature, though it may easily be overestimated as an end in itself. When they are known, the student observes for himself the motions described in the text. Therefore it is best to have those groups that are visible learned in the beginning. After this it is not necessary to take more than a few moments from book-study, in order to call the student's attention to any phenomena in the heavens which it is desirable he should see.

Of course, as other constellations come into the evening sky in the east, they must be learned. The occasional suspension of book-study for one clear night will be sufficient in order to keep up with changes.

Where there is no time to have all the constellations studied in class, the polar and zodiacal star-groups, and those containing first and second magnitude stars, should be selected. As the constellations of the zodiac are not all conspicuous, their superior importance may be overlooked by an inexperienced teacher.† They should be learned as soon as possible.‡ When the student knows them separately, he should at once begin to draw them on the ecliptic. He should draw the line first, and then the star-groups on it in correct order and position. Students should often be required to draw the zodiac and ecliptic on strips of paper in a few moments. It is a good plan to have the line occasionally drawn on a long blackboard, and divided into twelve parts, and to send twelve students together to draw figures rapidly, giving them no warning as to which they are to draw, and timing them. But it is not desirable to draw the constellations on the equinoctial and colures, until the student has been very familiar with the ecliptic for a long time. The ecliptic is the important circle, and an imperfect knowledge of the equinoctial and colures would poorly compensate for a failure to be very familiar with the ecliptic. Therefore, the other circles should not be studied until there is no possible chance of getting confused with the ecliptic.

I hope I may be pardoned for telling of a test to which I put this method of teaching constellations. I took a class of fifteen children, whose average age was twelve years, but of whom three were only eleven years old, and I began to teach them the constellations at the beginning of the school year in September. Until a test was made at the beginning of November, I was never with them at night on a single occasion, nor had they any one at home who gave them help. They simply drew the figures and stars, and were drilled as here described. There was a good deal of bad weather, and another study took the place of star-learning, at least a third of the time. The lesson was half an hour long. At the first of November they knew perfectly every constellation which had been visible. They could tell where all the first and second magnitude stars were found. They knew nearly every third-magnitude star and a good many fourth. They could trace the ecliptic in the heavens, or draw it. They knew Algol, Mira, Epsilon Lyræ, the star in Draco which was the pole-star; Var in Aquila, midway between the poles; and what made them all remarkable. They knew the points where the sun is found, December 22d and March 21st, and their names. They found no difficulty whatever in learning Pisces and Aquarius. Some had a little trouble with Hercules and Ophiuchus, but finally found them. They noticed the daily and annual motion of the stars, the revolution of the moon and her motion among the stars, and they watched with great interest the motion of Venus among the stars. They also noticed that the constellations of the zodiac seemed to approach the sun in succession, and other points not necessary to mention. Their enthusiasm was very great, and I am sure they are observers for life.

This book is, of course, not intended for children, and the subject is only mentioned to show what can be done by the method here recommended of promoting observation.

In schools, where advancement depends on examination, observation-work will almost inevitably suffer, unless there is also an examination in it.

For the benefit of inexperienced teachers, it is well to give some advice in regard to the constellations which it is best to begin with. Of course, the Great Dipper, the Little Dipper, and Cassiopeia should come first. Chapter II contains directions how to learn them. After these are learned, some conspicuous constellation must be selected and found, and the rest of the study proceeds from that by adjacent constellations. For the three autumn months, Pegasus is best; for the winter months, Orion; for spring, Leo Major; for summer, Scorpio. By finding these in the "Description of Constellations alphabetically arranged," Appendix A, the learner and inexperienced teacher will find hints how to proceed.

Most teachers without experience in observation-teaching will, when using this book for the first time, secure only part of the observation-study. The book can be used for a mere cram-book, and I have endeavored to make it stimulate the student even in that case, and give him power and zeal to help himself. Every teacher should try to secure some beginning of observation, and with each successive class the work will increase.

A school year devoted to astronomy will give very admirable results; but with five months, work can be done well worth undertaking. It will be good work if a class sees enough of the daily motion of stars to perceive that it is a revolution with the pole for a center; enough of the annual motion to see that stars watched at intervals of two or three weeks at the same hour move west, disappear beyond the western horizon, and reappear above the eastern; some motion of the sun on

* This plan would be modified by bad weather, making observation impossible.

† The minuteness of these directions is intended for this class, whom the author hopes to aid. It is no reflection upon others.

‡ The facts which show that the earth and planets revolve round the sun can be seen by anybody with eyes. The reasoning which establishes this theory, and the connection of these facts with it, are so simple and plain that any high-school student learning geometry can understand them clearly. Thus he can look at the changes in the heavens with intelligence. But this whole result depends on knowing the constellations of the zodiac.

the horizon ; something of the increasing or decreasing obliquity of the sun's rays. The moon comes so conveniently for observation that, where it is possible, I recommend that she be studied through an entire lunar period from night to night. This work trains in observation, and the knowledge in nature, of the important positions, opposition and conjunction, is useful when the pupil studies the planets.

This observation-study can be directed without going out with students at night at all.

No elementary science is so independent of expensive apparatus in schools as astronomy. The Copernican theory is the groundwork of all formal treatises on astronomy, and its author died before the invention of the telescope. No telescope, used in ordinary schools could aid in its rational acceptance, except by showing the phases of Venus and the moons of Jupiter. The bearing of these on the theory could not be at all appreciated by a person who had not previously studied what can be seen with the naked eye. It is, of course, a pleasure and advantage, after learning what can be seen without a telescope, to see these objects, and also the rings of Saturn, the surface of the moon, and the resolution of some nebulæ ; but I doubt whether it is any advantage at all until the student has used his unaided eyes. The most important need for high-schools seems to me to be some simple means of taking angular measurements on the heavens. This brings out a little the relation of the study to mathematics.

Of course, a large part of the information in any elementary astronomy comes from investigators equipped with the refined and complicated instruments of modern observation. In this case ordinary people can not see for themselves, but must take the facts on testimony. But here the phenomena seen can be so well represented by picture that ordinary people are under no great disadvantage in following with intelligence the conclusions of astronomers. Of course, we could neither intelligently accept the evidence nor appreciate the conclusions if we are entirely ignorant of the principles on which the instruments are constructed ; but these can be easily understood by the aid of a few inexpensive mirrors, lenses, and prisms.

It is my own experience that young persons have a sort of superstition about apparatus which looks complicated, and especially as if it cost a good deal of money. The feeling is diametrically opposed to the spirit of investigation, and therefore until they have become possessed of that spirit it is best to teach them with the simplest appliances.

Of illustrative apparatus, a globe, with the ecliptic traced on it in connection with the equinoctial system of circles, is important; but there is a very small, cheap terrestrial globe now much used in primary schools which has the ecliptic traced on it for the purpose of using the globe to show the circles on the heavens. It can be made to answer the purpose, using an India-rubber band for the horizon when we wish to show the angles it makes with the ecliptic. The celestial horizon in nature is such a well-defined circle, and the sphere so plainly revolves through it, that there is not much lost by the globe not revolving through the India-rubber band. Of course, a good celestial globe is a great advantage, provided it does not take the place of nature-study. Where we can see for ourselves, illustrative apparatus is useful only to give definiteness to our ideas derived from observation; but the study of nature should come first. I have many times seen expensive illustrative apparatus used so as to discourage observation. This was not intended, but practically this was the result.

N. B.—The various figures on the maps sometimes occur on more than one map. For the student to copy, it is best to take them from maps where they are found on or near the middle of the map.

NOTE.—In using Charts I, II, III, IV, it is best to forewarn students that, where figures must be represented very small, as on these charts, the stars appear relatively somewhat larger than in nature. A teacher will always find it wiser for students to draw on a larger scale. The figures on the chart facing page 10 are on a very good scale for their drawings.

The fuller charts at the end of the book are for reference after the student has learned the brighter stars in the constellations, by means of Charts I, II, III, IV. The dotted lines show the boundaries of constellations, the Greek names of stars are given, and there is a fuller representation of the stars. The student's attention should be called to the fact that these charts represent the northern and southern hemispheres, the north pole being at the zenith.

MAP I.

For Study of the Stars from January 20th to April 20th.

CAUTION.—Be sure to read the directions for using these maps, given in the Introduction, page 5.

THE HEAVENS

AS SEEN

December 22d at midnight,
January 20th at ten o'clock,
February 4th at nine o'clock,
February 19th at eight o'clock.

tance between two points in a straight line is called the minor axis. The eccentricity of an ellipse will perhaps be best understood by saying that it is the degree in which the ellipse differs from a circle. An ellipse is drawn by fastening two ends of a string to paper firmly secured to a board, and by then placing the point of a pencil against the loop and revolving it. (See Fig. 9.) The ellipse in which the earth moves can hardly be distinguished from a circle. The sun is at one of the foci. (See Figs. 10 and 11.)

FIG. 11.

The Earth's Orbit.

47. **The Sun and the Ecliptic.**—We know, from the western motion of the stars, that the sun falls back among them. Neither sun nor stars really move. They only appear to change position in regard to each other in consequence of the earth's motion. This is called the motion of the sun in the ecliptic. When the stars seem to change place in regard to the horizon, it is called the motion of the stars. In a year the sun falls back completely around the ecliptic, and this is called the sun's revolution on the ecliptic. In speaking of this motion, we can say that the sun moves northeast or southeast on the ecliptic, since it is a revolution. But there is no appearance whatever of an annual revolution of the sun *round the earth*, and so we speak of his motion on the horizon as a motion north or south.

Let us suppose that it is sunset, and that a line is drawn through the earth and the sun to the stars beyond both. It would reach points of the ecliptic 180° apart. We should see the sun at the western end of the line, and, if there were an observer at the sun, he would see us at the eastern end of the same line. The two positions, that of the sun as seen by an observer at the earth, and that of the earth as seen by an observer at the sun, would always be 180° apart. The observer at the sun would seem to see the earth move on the ecliptic.

The daily and annual motion of the sun go on together. He revolves daily with the sphere, and also moves among the stars on the sphere. This can be illustrated by supposing an ant to walk eastward round a globe, while the globe revolves westward and carries the ant with it. It is perhaps better illustrated by the moon, which revolves daily with the starry sphere, rising and setting, and also moving among the stars on the sphere. Her daily motion is westward, like the sun's, and her motion among the stars is eastward.

48. The sun's revolution on the ecliptic measures our year, and for this reason that circle is divided off in degrees and used for celestial measurements. Circles parallel to the ecliptic are called Celestial Parallels, and circles perpendicular to it are called Celestial Meridians. Distances from the ecliptic are called Celestial Latitude. Celestial Longitude is distance measured east on the ecliptic from the intersection of the ecliptic and equinoctial in Pisces. (See Map III.) Right ascension is reckoned on the equinoctial east from the same point. On the earth longitude is counted both east and west to 180°, but on the heavens right ascension and longitude are reckoned east only, to 360°.*

Thus there are three systems of circles for celestial measurement, viz., the Horizon System, the Equinoctial System, and the Ecliptic System. All have their uses.

49. The extreme southern point of the ecliptic in Sagittarius (see map) is reached by the sun on December 22d. Both the time and the place on the heavens are called the Winter Solstice. The sun reaches the extreme northern point of the ecliptic in Gemini (see map) on June 22d. The time and the place are each called the Summer Solstice.

Since the sun is due west at sunset on March 21st and September 21st, he must then cross the equinoctial, which intersects the east and west points of the horizon. The sun crosses in Pisces (see map) on March 21st, and the time and the place are each called the Vernal Equinox. The sun crosses in Virgo September 21st, and the time and the place are each called the Autumnal Equinox.

A great circle of the Equinoctial System passes through the poles and the equinoctial points of the ecliptic. It is called the Equinoctial Colure. Another passes through the poles and the solstitial points, and is called the Solstitial Colure. Both are represented on the maps.

50. **Observation of the Ecliptic.**—It is impossible to have a practical knowledge of astronomy without knowing the ecliptic in nature. It is constantly unrolled be-

* Since declination and right ascension, like terrestrial latitude and longitude, measure distances north and south, east and west, it would have seemed more appropriate to call them latitude and longitude. But names in use can not easily be changed, and the very incongruity fixes in memory the use of the terms.

fore us. Maps and globes aid us in preparing for intelligent observation, but it would be very absurd to substitute a knowledge of these for intelligent acquaintance with the circle in nature.

The ecliptic has four chief aspects: At sunset on June 22d it extends from northwest to southeast, and at sunset on December 22d it stretches from southwest to northeast. Of course, we can not see this at sunset. But, at different times, these aspects are seen at all hours of the night. When they are visible, Sagittarius is always on one side of the horizon, Gemini on the other. Maps III and IV do not show the exact aspect for this season.

At sunset, March 21st, the ecliptic extends nearly over our heads across the sky, and at sunset, September 21st, it makes a long curve toward the southern point of the horizon. Maps I and II show exactly these aspects with Pisces and Virgo on the horizon. Like the two other aspects, these are, at different times, seen at all hours of the night. In observing them the student must particularly note that, on March 21st, the ecliptic is very nearly perpendicular to the horizon, and that it is very much inclined to the horizon on September 21st. When these aspects are seen, Pisces and Virgo are always on the horizon.

About a month before the time of the solstices and equinoxes, there is a favorable opportunity for observing the chief aspects at a convenient hour.

It is of great aid, in giving definiteness to the student's ideas, if he can see the ecliptic traced, in connection with the equinoctial system of circles, on a revolving globe. The small globe spoken of in the Introduction will answer the purpose.

Let the student turn to Map II. It shows that, during the six months before September 21st, the earth moves first southeast, then east, then northeast. Observation shows that at that time the sun moves on the horizon, first north, then appears stationary, then moves south. Now, when the sun appears stationary, the earth has certainly ceased to move north or south. But, since the stars continue to move west, the earth is not at rest. She must move due east. Also, the sun must continue to fall back on the ecliptic if the stars continue to move west. He must move due east. At June 22d, when the sun is stationary, the earth is in Sagittarius. The student can see on Map II that the course of the ecliptic through Sagittarius is nearly east and west. The sun at that time is in Gemini, and Map I shows that the ecliptic also runs nearly east and west through Gemini.

NOTE.—The following sections should be omitted, unless the student's knowledge of geometry, as taught in all high-schools, is thorough. Where it is, the student is perfectly prepared to understand what follows, with due study, and, unless the time is too short, it ought not to be omitted. If the student is to know the ecliptic in the heavens, he ought to understand how it is traced. The student should point in reciting.

51. How the Sun's Motion among the Stars is measured.—The meridian of any place is a great circle passing through its poles on the heavens, its zenith, its nadir, and the north and south points of its horizon. It revolves with the earth around its axis. We know the exact time of a revolution, the distance (360°), and therefore the rate of motion. Therefore in a given time we can tell exactly how far in degrees the meridian has moved. By observation we learn the interval of time between two successive appearances of the sun on the meridian, and we can tell the distance in degrees through which the meridian has passed in the interval. It is always more than 360°, for while the meridian revolved back to the point where the sun was, the sun moved east on the ecliptic, and the meridian must revolve farther to catch up with the sun. Subtracting 360° from the whole distance, we get the number of degrees the sun traveled east among the stars in a solar day.

When the sun is on the meridian above our heads, we can measure his distance in degrees from the south point of the horizon with an instrument for measuring angles. By finding this distance daily, we can detect his motion north or south. By adding to this distance the distance of the south point of the horizon from the celestial south pole, or the observer's latitude, we get the sun's distance from the south pole.

52. The Sun's Path shown to be a Great Circle.—Let the student examine the small globe used in 40 and note the following facts: (1) The equator, ecliptic, and meridians, each one, divide the surface of the globe into equal parts, and therefore they are great circles of the sphere. (2) All great circles bisect each other. (3) No small circle (as a parallel) bisects a great circle.

The meridian of any place is a great circle. The ecliptic is always crossing it at two points:* one above, one below the horizon. If the sum of the distances of these two points from the south pole always equals 180°, the sun's path bisects the meridian and must be a great circle. Now, the point below is 180° east of the point above; and, therefore, when the sun, starting from the point above, travels east 180°, he will be on the point now below. But astronomers have a great many times measured on the meridian the sun's two distances from the south pole at points of his path 180° east from each other, and the sum of these distances always equals 180°. Therefore the meridian, revolving over the ecliptic, is always bisected by it, and the ecliptic must be a great circle.

53. The Ecliptic traced among the Stars.—The meridian of any place is always crossed by the ecliptic above and below the horizon, and the arc of the meridian between these intersections equals 180°, since the ecliptic is a great circle. When the sun is on the meridian at noon, we can find the distance of the intersection above, from the south pole. (See 51.) Subtracting this from 180°, we get the distance from the south pole of the intersection below. In half the time of the earth's rotation, the intersection which was below is on the meridian above. We know its distance from the south pole, and subtract-

* The student who knows the ecliptic in nature has seen this.

ing from this the number of degrees measuring the terrestrial latitude, we get the distance of this intersection from the south point of the horizon. Measuring this ascertained distance north from the south point, we find the ecliptic point, and, as the stars are then visible, we have found it among the stars. Other points can be found in the same way.

CHAPTER IV.

INEQUALITY OF DAYS AND NIGHTS—THE SEASONS—THE PRECESSION OF THE EQUINOXES—TIME.

54. **Inequality of Days and Nights.**—The sun is at his highest northern position on June 22d, and in the United States the days are then at their greatest length; the nights at their shortest. As he moves south, the days grow shorter and the nights longer; but they do not become equal until September 21st, when the sun at sunset is due west, just at the point where the equinoctial cuts the horizon. He makes his daily journey then on the circle of the equinoctial. Finally, on December 22d, he has reached his extreme southern position, 23½° south of the equinoctial, and he makes his daily revolution on the circle of 23½° south. The days are then at their shortest, the nights at their longest. When he again begins his annual journey north, the days increase in length; the nights decrease, until March 21st, when the sun at sunset is again due west of us. He has again reached the equinoctial, and makes his daily journey on that circle. After that the days are longer than the nights, and finally, on June 22d, he makes his daily journey on the parallel of 23½° north.

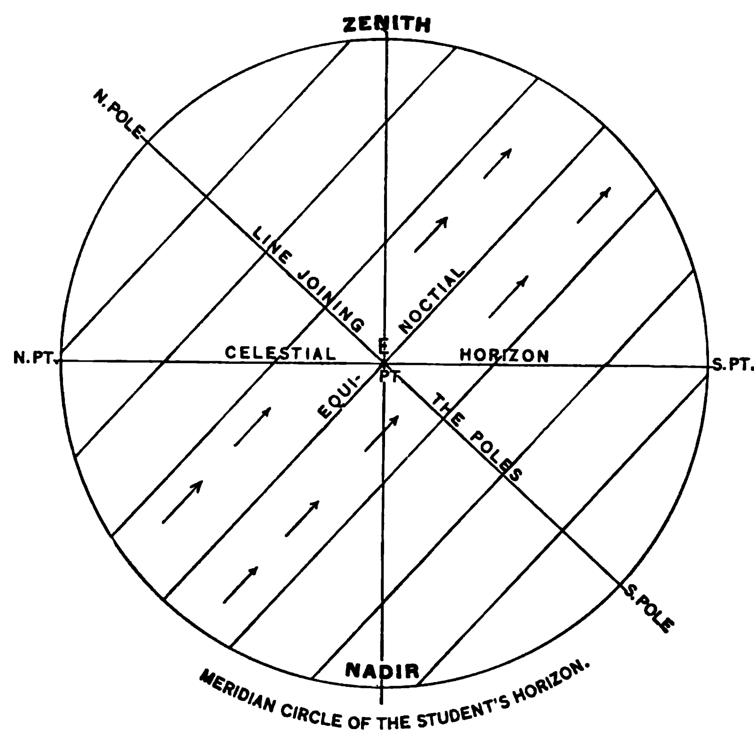
As we travel north, the times of the year for long and short days and days equal to nights do not change; but the inequality of days and nights increases until we reach the pole, where they become equal by the night and day each becoming six months long.

If we travel south, the inequality decreases, until at the equator days and nights are equal. If we continue our journey south of the equator, we shall find the days begin to differ in length as they do in the northern hemisphere, only the times are reversed; the long days coming in December, the long nights in June.*

55. In order to understand the precise connection of these phenomena with the sun's motions, the student must remember that the sun, in his apparent journey north and south, also makes at the same time apparent diurnal revolutions in circles parallel to the equinoctial. The parallels of that great circle are called *diurnal* circles, because sun and stars make their diurnal revolutions on those parallels. Now, these circles decrease in size, as the student remembers, in proportion as they lie farther from the equinoctial and nearer the poles. For this reason we can not learn anything about the sun's various daily paths over our sky above the horizon, by comparing the lengths of the paths made by stars across the sky. If we could compare the paths of stars at equal distances north and south of the equator, the circles would be equal and the comparison hold good. We must try to compare the two parts of the same circle, one above and one below the horizon.

56. We must draw a diagram of the eastern hemisphere of the student's own sky. The circle drawn be-

FIG. 12.

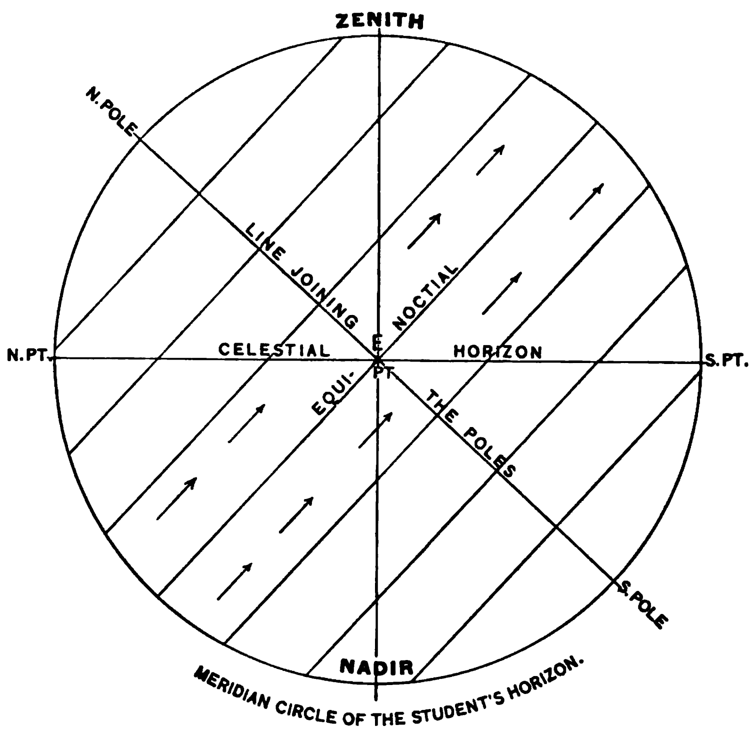


low, Fig. 12, is made from facts, every one of which is perfectly well known to him, and he is invited to consider all the lines in the order in which they were drawn, and attest the correctness of the representation. But he must understand that it is a diagram, *not* a picture. The heavens are in every place divided into eastern and western hemispheres by the meridian of the place, a great circle passing through zenith and nadir,

* The inequality of days and nights is here explained by arcs of circles on the celestial sphere, because the student sees this sphere and the motions of the sun and stars on it, and thus has some personal knowledge of the facts on which the explanation is based. It corresponds to facts he sees in nature. If we draw a figure of the earth with the light and shadow, he can not compare it with nature. He sees the connection between the facts and the conclusion, but he takes the facts solely on the authority of a book.

north and south poles, and the north and south points of the horizon. The eastern hemisphere of the student's sky is bounded by this great circle, the meridian; therefore we must first draw a circle. And this eastern hemisphere is divided into two equal parts, the visible part and the invisible part, by a line called the horizon. Therefore, we draw a horizontal line across the circle. The horizon intersects the meridian on the left in the north point; on the right, in the south point (observer facing east). The point of the horizon half-way between the north and south points is called the east point. We mark all these points on the diagram. The north pole is on the meridian above the north point. We shall put it at about 40° above the north point, because in a large part of the United States the altitude of the pole does not differ greatly from 40°. The south pole is on the meridian at the same distance below the south point of the horizon, so we draw it there. The celestial sphere has on it a great circle, the equinoctial, which is at every point on it half-way between the poles. It of course crosses the eastern hemisphere of the student's sky, and also the meridian. It must cross the meridian at points half-way between the poles. These points are found, and a line is drawn between them. It will be found to cross the horizon in the east point. Other circles cross the sphere parallel to the equinoctial. These are the diurnal circles, and, as we have the equinoctial, it is easy to draw some circles parallel to it.

FIG. 12.



The student probably says just here, "But the part of the eastern hemisphere which I see in nature is concave, and this looks flat." That is to say, the diagram is not a picture. It lacks perspective. The author did not want a picture, because perspective depends on illusion. It would alter the proportion between the parts of the diurnal circles lying above and below the horizon, and that proportion is the very thing we wish to know. The diagram shows this more truly than a picture would.

The sun is on the meridian below the horizon at midnight. He is on the meridian above the horizon at midday. He therefore crosses the eastern hemisphere between midnight and midday. We will draw arrows, indicating the direction in which he crosses it. We, of course, see only half of his daily revolution, on this eastern hemisphere of the heavens. But it is evident that the other half, on the western hemisphere, would correspond exactly with this. The period between sunrise and noon when the sun is on the meridian above us, a period which the sun passes in the eastern hemisphere, is exactly equal to the period between noon and sunset, which the sun passes in the western hemisphere. Therefore, it is only necessary to study one of the hemispheres. We will now discuss the diagram.

In March and September the sun is due east from us at sunrise, or at the east point of the horizon. He is on the equinoctial, and must make his diurnal revolution with it. On the diagram the portion of the equinoctial situated on the eastern hemisphere is divided into equal parts by the horizon. From midnight to midday the sun would evidently be just half his time above the horizon. This accounts for the fact that on March 21st and September 21st the nights and days are equal.

From March to September the sun is seen, at sunrise, north of the east point of the horizon, and must therefore make his daily revolution on circles lying north of the equinoctial. The diagram shows that less than half of each circle north of the equinoctial lies below the horizon. The sun, in traveling on them, would be above the horizon more than half the time. This accounts for the fact that, from March to September, the days are longer than the nights. The inequality between the parts of the circles lying above and below the horizon is greatest in those circles lying farthest north. We should therefore expect the inequality between days and nights to be greatest when the sun has reached his extreme northern position. This is true. The longest day comes on June 22d, and after that the sun again moves south.

From September to March we find the sun at sun-

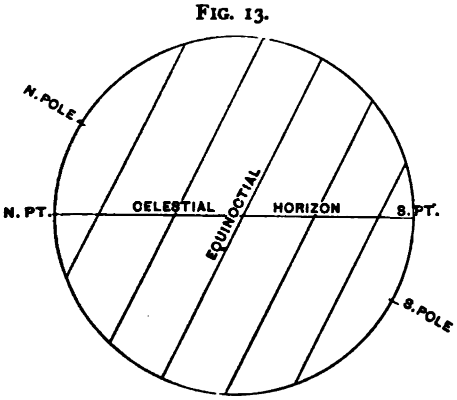
rise south of the east point. The nights are longer than the days. The sun now makes his diurnal revolution on circles lying south of the equinoctial. On looking at our diagram of the eastern hemisphere, we find that more than half of each one of these circles must lie below the horizon. This accounts for the short days and long nights from March to September. The division of the circles on the diagram is more unequal as they are situated farther south. This is evidently the reason why the shortest day, December 22d, comes when the sun has reached his extreme southern position.

The cause of the inequality of days and nights is evidently—1. The sun's north and south motion. 2. The unequal parts into which the diurnal circles are divided by a horizon which does not pass through the celestial poles.

57. Since all the people living on the terrestrial parallel of 40° north latitude have their poles 40° above the horizon, it is clear that this diagram would represent the eastern hemisphere of the sky for all of them. Our antipodes, or the people on the opposite side of the globe, see the part of the celestial sphere at any time invisible to us. That is represented by the part of the diagram below the horizon. The antipodes of all the people living in 40° north latitude live in 40° south latitude. Therefore, the lower part of this diagram represents the visible part of this hemisphere to the people on the terrestrial parallel of 40° south latitude. They would call this the "western hemisphere," but north and south on it are the same directions to them and to us. It is clear, from an examination of the diagram, why they have their long days when the sun is at the south, their short days when he is at the north. It is because their daytime comes when their antipodes have night.

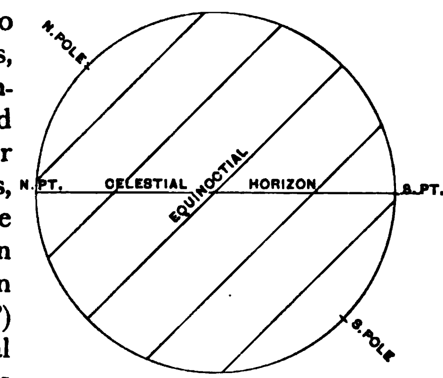
58. It remains to account for the fact that the inequality of days and nights increases as we move toward the poles, and decreases as we approach the equator. The two circles, Figs. 13 and 14, show the eastern hemisphere of the heavens at Quebec and at New Orleans. In drawing these diagrams, the change in the height of the poles made it necessary to alter the position of the equinoctial (which is half-way between the poles), and therefore of the diurnal circles. The student remembers that the equinoctial intersects the meridian midway between the north and south poles. The greater elevation of the pole at Quebec makes the equinoctial and other diurnal circles more oblique to the horizon, which therefore divides them into more unequal parts, thus increasing the inequality of days and nights. On the other hand, at New Orleans, the depression of the pole (in comparison with its positions in latitudes 40°, 45°) makes the equinoctial and diurnal circles more nearly perpendicular to the horizon. The two parts of the diurnal circles are less unequal than in Quebec, and therefore days and nights are more nearly equal in New Orleans.

FIG. 13.



DIURNAL CIRCLES AT NEW ORLEANS.

FIG. 14.



DIURNAL CIRCLES AT QUEBEC.

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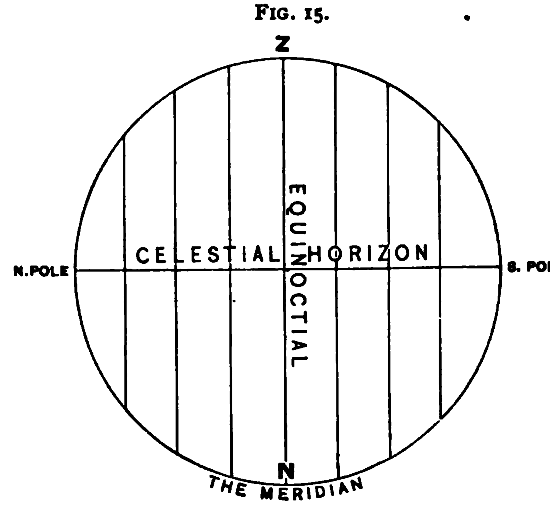
59. The student must take note that in all three of the diagrams the equinoctial is cut into equal parts by the horizon. The celestial horizon is everywhere a great circle of the celestial sphere. Great circles of the same sphere always bisect each other.* Therefore, the equinoctial is in every place divided by the horizon into equal parts. For this reason, whenever the sun makes his daily journey on the equinoctial, as in March and September, days and nights are equal all over the world.

60. The diagram (Fig. 15) shows the eastern hemi-

FIG. 15.



* The student may prove this with the small terrestrial globe. A great circle of a sphere divides its surface in half. The student can not pass a thread round the globe, so as to divide its surface in half, without thereby bisecting the equinoctial, ecliptic (so called), and meridian circles.

The terrestrial circles called the Tropics of Cancer and Capricorn, and the Arctic and Antarctic Circles, all indicate the sun's movements. The Tropic of Cancer is the extreme northern parallel on which the sun shines vertically; the Tropic of Capricorn the extreme southern parallel. The Arctic and Antarctic Circles mark the boundary of sunlight when the sun is vertical over the Tropics.

63. **The Annual Change of Temperature.**—In order to understand thoroughly some of the effects of the sun's motions, the sun should be observed at noon on June 22d, and also on December 22d. This statement must be accompanied by a warning against looking at the sun with unprotected eyes. It is in the highest degree dangerous. For the present purpose, observation can be very conveniently made through a thin umbrella.

The object of the observation is to note the sun's variation in altitude above the south point of the horizon, and its distance from the zenith.

In order that the description of the sun's motions may excite real and definite ideas, the student should go out of doors while studying this part of the book, and look at the heavens as now to be directed. Let him first look at the zenith. In the United States the sun's position on June 22d is a little south of the zenith. As the student looks at this point, he takes note that a line drawn from it to himself would be, not quite vertical, but a little oblique. Let him next look at a point about 30° from the south point of the horizon; that is, about one third the distance from the horizon to the zenith. In a large part of the United States the sun, on December 22d, is at least 60° from the zenith. As he looks at this point, let him note that a line drawn from it to himself is much more oblique than a line drawn from the sun's position of June 22d.

64. Let us now consider some other facts. The sun's annual journey from north to south coincides with a change of temperature, called the "change of the seasons." There is always, from January to July, a general increase of heat; from July to January, a general decrease. It is true that summers differ in regard to heat, while some winters are colder than others. If, also, we select periods of two or three weeks, it is not true that the day nearest to January will always be coldest, the day nearest to July always warmest. These variations lead us to think that the sun's motions are not the *only* cause affecting the seasons. But since summers are always warmer than winters, we are led to think that the sun's north and south journey is the cause of an *annual* variation of temperature.

65. We gain some further knowledge of the sun's effect on the temperature by traveling north or south. As we journey northward, the severity of winter increases, and the heat of summer decreases. As we travel southward, the contrary effect is perceived, until we reach the equator. After crossing that circle, the effects of moving north and south, as seen north of the equator, are reversed.

Now, it is evident that, as we travel farther north, the sun would seem to more farther south, and thus the obliquity of the sun's rays would increase. Travelers report to us that this is the case; and thus again a decrease in heat coincides with increasing obliquity of the sun's rays. As we go toward the equator, the obliquity decreases, in conjunction with the experience of warmer weather. After we cross the equator, and travel toward the south pole, the climate becomes colder and the sun's rays more oblique.

66. We have, besides this, a daily experience of increased heat coinciding with a diminishing obliquity of the sun's rays. In the early hours of the morning the sun's rays are very oblique, and the heat regularly increases as the sun becomes more nearly vertical. All these facts make it impossible to doubt that the varying obliquity of the sun's rays, caused by his north and south motion, is the direct means by which the annual change of temperature is effected.

67. If the varying obliquity of heat-rays changes the degree of warmth which we feel, it ought to be true of rays from other sources of heat than the sun. If the student will wet two pocket-handkerchiefs of equal thickness, and hang them up before an open fire in positions equally favorable for receiving warmth, except that one is hung parallel to the fire, the other in an oblique or slanting position, he will find that the one hung parallel will dry first.

68. It may seem an objection to this reasoning that the coldest weather comes about a month after the winter solstice at December 22d, and the warmest about a month later than the summer solstice at June 22d; and also that the warmest period of the day is a good deal later than twelve o'clock. But this is only in unison with the fact that on a cold day, when one is perfectly warm and comfortable, and goes out into the cold, he does not at once reach his coldest feeling. Also, when we take a hot walk in summer, we do not at once cool off on getting into the house. The explanation of these things is, we both lose and gain heat gradually. They do not affect the proof that the varying obliquity of the sun's rays, caused by his movement north or south, is the cause of the annual change of temperature which we call "the Seasons."

69. Other causes modify the variation of temperature caused by the sun's obliquity. Thus the climate of a

place is affected by altitude above the level of the sea, distance from the sea, and the character of the prevailing winds. In going north or south, we may find some of these causes more effectual in some places than the sun's increasing or decreasing obliquity.

70. The heat of summer is evidently much affected also by the length of days, causing heat to accumulate, since we gain and lose it gradually. As we travel north, the days and nights grow more unequal. For this reason it is often found that Quebec or Montreal will report, on one or two days in July, the mercury at a higher degree in the thermometer than Charleston or Savannah. But the general, or average heat of the summer is much greater at Charleston and Savannah, and the season longer.

71. The student remembers that the apparent diameter of the sun is greater in our winter than in our summer, indicating that the sun is in perigee, or nearest to the earth, in winter, and in apogee in summer. Our experience shows that our distance from the sun does not vary enough to counteract the effect of variation in the obliquity of the sun's rays. But in the southern hemisphere the earth is in perihelion in summer, in aphelion in winter. If, now, the variation in our distance from the sun affects the earth at all, it might be expected to make the extremes of temperature in both winter and summer a little greater in the southern than in the northern hemisphere. It takes long, careful, and widely extended observations to settle this question; for in going from one locality to another, altitude, distance from the sea, and prevailing winds, all affect the climate of a place; but it is considered certain that the winter and summer of the southern hemisphere are both more extreme than the seasons of the northern.

72. **Inequality in the Sun's Motion.**—The earth does not move in her orbit through equal distances in equal times, and, of course, the sun moves with unequal speed in the ecliptic. This is learned in the following way: When the sun is due west at sunset, he is crossing the equinoctial. Now, astronomers, by watching the sun exactly at the time he crosses the meridian at midday, and then taking his angular distance from the south point of the horizon, can tell with minute accuracy when he crosses the equinoctial, since they know exactly how far it is from the south point of the horizon. They find the sun on the equinoctial twice a year, in March and September. As the points where the equinoctial intersects the ecliptic are 180° apart on each circle, it is evident that, in the intervals between the sun's two passages across the equinoctial, he has traveled through equal spaces. But the student may count the days from March 21st to September 21st,* and then again from September 21st to March 21st, and he will find the first interval a few days the longest. From March to September, the sun travels north of the equinoctial, therefore he takes a longer time to pass over the 180° lying north than the 180° south of it. The times being unequal, and the distances equal, the rate of motion varies.

73. By looking in the almanac, the student will find the words "☉ in perigee," "☉ in apogee," in December and July. These words indicate the times of the earth's smallest and greatest distances from the sun. The time when the earth moves fastest thus coincides with her greatest approach to the sun. Astronomers attribute the earth's varying speed to a variation in the attraction of the sun produced by his varying distance from her.

74. **Slow Changes of Motion.**—The earth's motions undergo some changes so slow that the observations of many generations of astronomers are needed to detect and know them accurately. Two will be mentioned here.

75. The earth is in perihelion, or at the point of her orbit nearest the sun, very nearly at the time of the winter solstice.† But the times of perihelion and aphelion come a few minutes earlier every year. In the course of several thousand years, the earth's perihelion will have revolved round the year until it comes at the time of the autumnal equinox, when the climates of the northern and southern hemispheres will become equalized. After a still longer period the time of perihelion will come in the summer of the northern hemisphere. That difference in the climates of the two hemispheres which is caused by the variation in the earth's distance from the sun will then be reversed (see 71). Finally, the perihelion-point will revolve back to its present position, and the present climates will be restored. If a line be drawn between the points of perihelion and aphelion, the effect of this change is to make it revolve. The change is called a revolution of the line of apsides.

76. **Precession of the Equinoxes.** — Astronomers, watching the sun's motions with a patience, carefulness, and persistence of which students can form little idea, discovered that the sun does not cross the equinoctial at the same points of the ecliptic, but a little farther west every year, and, of course, a very little sooner. The difference is only 50″, but in about twenty-five thousand years it will make the equinoctial points revolve round the ecliptic. They also found that certain stars

* Owing to our way of measuring time, we can not get the difference in time quite correctly in this way. Still, the difference is on the right side, and the student will realize better what he is studying if he actually counts the days.

† The student must find in the almanac the words "☉ in perigee," "☉ in apogee."

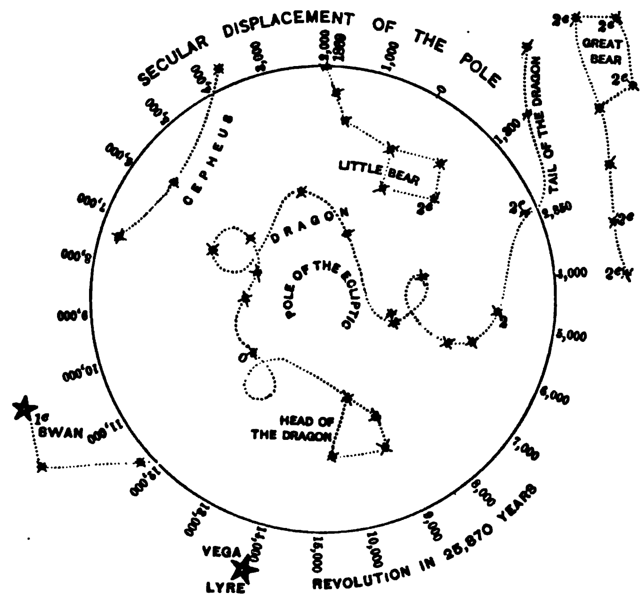
round the north pole seemed to be moving in circles of increasing size, and certain others in circles of decreasing size. Since the size of the circles depends on the distances from the poles, this indicates some change in the points of the heavens between which the earth's axis extends. Since the pole is 90° from every point of the equinoctial, it is evident a change in the position of that circle must change the places of the poles, or centers of apparent motion in the heavens.

77. While the equinoctial points move west round the ecliptic, the pole of the heavens describes a circle with a radius of $23\frac{1}{2}°$ around the pole of the ecliptic. The student may easily understand how this is by a little study of one of the small globes now very generally used, and having a circle, called the ecliptic, marked on it. By holding the globe so that the ecliptic circle is perfectly horizontal, the pole of the ecliptic is at the top, and it may be marked with a little wax, so that it can be identified. Then the axis is made perpendicular, and it will be seen that the pole of the ecliptic revolves around the north pole of the globe when the globe is revolved. Let us suppose now that the ecliptic moved round on the sphere, not with it. It is clear that it would have precisely the positions in space which it had when it revolved with the sphere, and, of course, its pole, which is 90° from the ecliptic itself, would have precisely the positions it did when ecliptic and sphere revolved together—that is, the positions *in space*. And it is clear that as the ecliptic would slide round the sphere, the points where it intersects the equinoctial moving round the equinoctial, so the pole would slide round the north pole, making a circle on the sphere.

Now, in explaining this, we have made the ecliptic move on the equinoctial. This was done only because the globe revolves round the poles of the equator, and could not be made to revolve round the poles of the ecliptic. But in the heavens, the student must remember it is the poles of the ecliptic which are at rest, and the poles of the equinoctial, in this very slow change of which we speak, revolve round the poles of the ecliptic on the celestial sphere. Since the north pole of the ecliptic is distant $23\frac{1}{2}°$ from the north pole of the equinoctial, it is clear that the circle described by the pole of the latter would have a radius of $23\frac{1}{2}°$.

78. From these facts it is clear that the centers of motion on the celestial sphere, or the poles of the heavens, are all the time changing place, but so slowly that the north pole will not complete a revolution in less than twenty-five thousand years. The map appended (Fig. 20) shows the position of the circle in which the pole is moving. The cipher shows the place of the pole at the beginning of the Christian era. The figures to the right show the position of the pole in years B. C. Those to the left show the position in years A. D. It can be seen that Polaris will be at the center of motion in the year A. D. 2000. In 2850 B. C., a star in Draco was the pole-star. This is supposed to be about the time when the Great Pyramid was built. The star Vega in Lyra, of the first magnitude, must at one time have been very near

FIG. 20.



the pole. Since the radius of this circle is $23\frac{1}{2}°$, it is clear that the present pole-star will one day be 47° from the pole.

79. When the ecliptic was first laid off in degrees, the circle was divided also into twelve parts called signs, and containing 30° each. The signs were named for the constellations they were then in, viz., Aries, Taurus, Gemini, Cancer, Leo, Virgo, Libra, Scorpio, Sagittarius, Capricornus, Aquarius, and Pisces. Since then, by the precession of the equinoxes, the signs have moved out of the constellations from which they took their names, but they have not changed names. Thus, the intersection of the two great circles is called the "first point of Aries," though it is in the constellation Pisces. The same names are used for both signs and constellations; and when we hear them, it is necessary to be careful in understanding which is meant, since they no longer coincide. When the terms are used in almanacs in regard to the sun's motions, the signs, not the constellations, are meant.

80. When the Tropics of Cancer and Capricorn were named, the winter solstice, at which time the sun is vertical at the Tropic of Capricorn, took place when the sun was in Capricornus. Also, the sun was then in Cancer when he was vertical at the Tropic of Cancer; that is, at the summer solstice. But the precession of the equinoxes has changed that. On the 22d of June the sun is now in Gemini, not Cancer; and on December 22d he is now in Sagittarius, not Capricornus. But the names are retained for the two circles.

Since Celestial Longitude and Right Ascension are reckoned from a movable point, the Celestial Longitude and Right Ascension of all stars are slowly changing. Since the pole changes, Declination also changes.

81. Time.—Even savages need to measure time in some rough way, and as the concerns of civilized life become complicated, men want measures of time which shall be conspicuous in their application, and also accurately adapted to men in all places and all centuries. The conspicuous measures of time, corresponding also to the practical affairs of life, are a revolution of the seasons, and an apparent diurnal revolution of the sun round the earth. Civilized nations early began to use these, and a desire to know them and to make our divisions of time accurate, encouraged the study of astronomy.

A revolution of the seasons is not exactly equal to a revolution of the earth in her orbit round the sun. If the earth were between the sun and that point of the ecliptic which is now crossed by the equinoctial, she would have made a revolution round the sun when she again came between the sun and that point of the ecliptic. But since the equinoctial does not continue to cross the ecliptic at the same point, but crosses earlier, it is plain that the earth will get back to the new crossing before she comes in line with the stars, and the point where she formerly crossed. This results from what is called the precession of the equinoxes. The interval between the two times when the earth passes between the sun and any point of the starry heavens is called a Sidereal Year. The interval between two passages over the same equinox is called a Tropical Year, and it contains exactly one revolution of the seasons. A sidereal year contains 365 days, 6 hours, 9 minutes, 9 seconds. A tropical year contains 365 days, 5 hours, 48 minutes, 46 seconds. The difference is very small, and would for a long time occasion no inconvenience if the year of our calendar corresponded with the sidereal year, but in time it would make the seasons begin on very different days and hours from those which now mark their beginning. Thus it is necessary to take the tropical year for the basis of our calendar.

82. The student recalls the fact that a solar day is longer than a sidereal day. We have, in this chapter, discussed the inequality of days to nights, using the word day to refer to the period of light in distinction from the period of darkness. We shall now use it to refer to the apparent diurnal revolution of the sun round the earth. It is the interval between two passages by the sun over the meridian below the horizon.

83. The meridian of any place is a circle belonging to the horizon system of circles. It revolves with the earth on her axis, passing through every point of the ecliptic, yet all the time passing through our zenith and nadir. Let us suppose the sun to be on the half of the meridian which is below the horizon. The meridian, of course, passes through a certain point of the ecliptic, since the sun is always on the ecliptic. The meridian makes a revolution along with the earth, and reaches the point of the ecliptic where it left the sun. The sun, which all the time moves east on the ecliptic, is no longer at that point, but further ahead. Now, the student remembers that the earth in her orbit does not move through equal spaces in equal times. Of course, the sun's motion in the ecliptic, which is due to the earth's motion in her orbit, is of unequal speed. Sometimes he will be farther ahead than at other times, and as the meridian, moving by the earth's diurnal motion (which does carry her through equal spaces in equal times), sometimes meets the sun sooner, sometimes later, the solar days vary in length. But they vary from another cause. The meridian moves due east, but the sun in the ecliptic does not move due east. His motion is compounded, the student remembers, of motions east and north or south, and sometimes he moves more directly east, sometimes his motion has more of a northern and southern direction, even though he moves through the same distance in both cases. When his motion is nearly east, as at the solstices, it takes the meridian longer to catch up than when his motion is nearly north and south, as at the equinoxes. For this reason the solar day (which is a period of both light and darkness) varies in length, being longest at the solstices, when it takes longest to catch up with the sun.*

84. On account of this variation in the length of the solar days, the *day adopted for our calendar is the mean, or average, of all the solar days in a year.* An hour is the twenty-fourth part of a day.

85. For this reason clock-time and sun-time do not always agree—or, in other words, mean solar time and apparent solar time do not always agree. But the almanac always tells us how they differ. (It is impossible to study this book well without actually using an almanac.) If we turn to February 10th, we find from the almanac the time of sunrise and sunset given according to our clock-time. But if we subtract from twelve, the hours and minutes given for sunrise, in order to find out how long it is before twelve o'clock, we should expect, if our

* There are two things the student must not get confused. Days (periods of light) are longest and shortest at the solstices, because their length depends on the sun's north and south position. Days (periods of time between the sun's passage of the meridian below the horizon) are longest at the solstices, because their length depends on the sun's eastern motion, which is greatest at the solstices.

twelve o'clock corresponded with the sun's passage over the meridian above us, to find it equal to the hours and minutes given for sunset. The sun must reach the meridian half-way between sunrise and sunset. Thus we should find that, on February 10th, a good watch, set by the sun at sunrise, would not reach twelve at the time the sun crossed the meridian. On February 10th the student will find that the interval between sunrise and the noon of the clock, is full thirty minutes longer than the interval between the same noon and sunset. In a column at the side of the record of sunrise and sunset, and under the heading "Sun Slow," will be found the figure 15. If this be subtracted from the longer period and added to the smaller, either will then give the true time of the sun's passage across the meridian, which is found to be fifteen minutes later than twelve o'clock. Because the sun comes to the meridian later than the twelve of clock-time, he is said to be "slow." The column of figures is called the "equation of time," because adding and subtracting it makes the morning and afternoon periods, as reported by the almanac, equal.

By studying the sunrise and sunset figures of November 2d, we perceive another discrepancy. Here the almanac tells us the sun is "fast"; that is, he crosses the meridian before the twelve of our clocks and watches set by the almanac figures for sunrise. The figures under the sun column "fast" must be *added* to the afternoon figures and *subtracted* from the morning figures. The difference between sun and clock time is greatest February 10th, November 2d, May 14th, and July 25th. Four times in the year the almanac reports no difference between the sun's actual passage across the meridian and the twelve of the clocks. These days are April 15th, June 14th, August 31st, and December 24th. The solar and the calendar day are then equal.

86. After we accept the mean solar day and the tropical year for the basis of our calendar, another difficulty arises. For practical purposes it is necessary to have our year exactly divisible by our day. Now, in the tropical year, there are 365 solar days, 5 hours, 48 minutes, 46 seconds.. The Romans at first made 365 days a year, but the repeated neglect of hours, minutes, and seconds every year, made an increasing error, so that in the time of Julius Cæsar the interval of a year no longer corresponded with a revolution of the seasons. Cæsar added a day to every fourth year (or six hours for each year). This year of 366 days, called by us "leap-year," is also called a "Julian year." The calendar, thus reformed, was used by Christian nations for about sixteen hundred years. This calendar is called "Old Style," or simply "O. S."

87. But since the tropical year is shorter than 365 days, 6 hours, this plan added too much, and after a while, March 21st got ten days ahead of the sun's passage of the equinoctial. Then Pope Gregory introduced, A. D. 1582, what is called from him the "Gregorian Calendar." This provides that "*every year divisible by 4 shall contain 366 days, except the centuries, which shall not be leap years unless they are divisible by 4 after striking off the two right-hand figures.*" Thus, 2000, 2400, 2800, are leap-years, but 1900, 2100, 2200, 2300, 2500, and 2700, are not leap-years, though divisible by four. Even by this rule, the years are not exactly divisible by days, but the error will not amount to a day in about three thousand years.

88. But it was necessary, in 1582, to get rid of the result of past errors, as well as to provide against future errors. The ten days which the 21st of March had got ahead of the sun's passage of the equinoctial were got rid of by calling the 5th of October the 15th.

89. The new mode of reckoning time is called "New Style," or "N. S." It was adopted at once by nearly all European nations. But the English people did not adopt New Style until 1752, when the error amounted to eleven days, which were left out of the year by calling the 3d of September the 14th. New Style has not yet been adopted in Russia.

90. Thus the year and day of our calendar can not in strictness be said to coincide with the tropical year and solar day. The interval between the sun's two successive passages over the same equinox, and the interval between the sun's two successive passages over the meridian below the horizon, are simply the *basis* of our year and day. Our years and days differ from the solar year and day, but some days and years are longer, some shorter. In the case of the days, the differences counterbalance one another exactly; in the case of the years very nearly. The coincidence is near enough for practical purposes.

NOTE.—In the almanac the signs of the zodiac have the following symbols:

♈ Aries	♋ Cancer	♎ Libra	♑ Capricornus
♉ Taurus	♌ Leo	♏ Scorpio	♒ Aquarius
♊ Gemini	♍ Virgo	♐ Sagittarius	♓ Pisces

CHAPTER V.

THE MOON AND HER MOTIONS, AND HOW TO OBSERVE THEM.

91. No other heavenly body offers so convenient an opportunity for full observation as the moon. She comes often, and goes through the round of her motions in a reasonable time. It is not only exceedingly interesting

work to watch her through a full revolution, it is excellent preparatory training for the observation study of the planets. The positions of the moon in relation to the sun and earth are similar to certain important positions of the planets in regard to sun and earth.

In order to observe the moon well, it is necessary to know at least those constellations of the zodiac which are in the evening sky. They can be learned in a few evenings by drawing them a good deal.*

It is best to begin observation as soon after the date given in the almanac for new moon as the observer can get a sight of her. It is very difficult to see the new moon before she is two days old.

There are three lines of observation which must here be treated separately, in order to avoid the confusion which results from describing several things at once. But the student must carry out all three together when he can study nature for himself.

I. The Moon's Motions.

92. **The Diurnal Revolution.**—At two or three days from the time of new moon, the moon will appear as a slender crescent, seen soon after sunset above the western horizon, and not far from the sunset-point. If, after finding her, the student will return in ten minutes to look again, he will see that she is moving toward the western horizon, and will disappear behind it soon after sunset. As all the heavenly bodies which the student has observed exhibit similar motions, he will recognize hers as apparent, and due to the earth's rotation on her axis. If so, the moon must cross the sky below the horizon during the twelve hours after her disappearance, pass above the eastern horizon a little after sunrise (invisible because of the sun's blinding light), and, crossing the heavens above the horizon during the day, reappear in the west when the sun's light is withdrawn. This is the moon's apparent diurnal revolution, and it is the cause of her rising in the east and setting in the west. As it is desirable to avoid any confusion of this motion with others, it will be best to make observations at the same hour every evening.

93. **The Moon's Real Motion.**—On the second night of observation, the student would find the moon again in the west, but she would be a little higher above the horizon, that is, a little farther east, than before. It is clear that the moon, or the horizon and earth, must have moved. If this motion is apparent, it must be caused by the motion of the observer and earth; and the earth must move west to cause it. But we know that the earth moves east. For this reason we conclude that this is a real, or, as astronomers call it, a "proper" motion of the moon. It causes the moon to change place among the stars every evening, while the diurnal revolution makes the moon move with the stars. It should be part of the student's observation-work to note the moon's place among the stars every evening, and thus detect her real motion.

94. **The Moon's Real Revolution. Opposition and Conjunction.**—Since the moon was found moving east, the student will, upon reflection, conclude that she must have come into the evening sky from below the western horizon, and, in doing so, must have passed the sun. She must have crossed a meridian circle running north and south through the sun's position. When she does this, she is said to be in conjunction with the sun.* She does not always cross this line exactly at sunset; but as she moves very slowly, she never gets far east from the sun at the very next sunset after it. So, after conjunction, we always see her near the western horizon at sunset. The moon becomes new after conjunction.

If the student continues to watch the moon's real motion at dark, he will find her every evening farther east among the stars; and in fifteen days she will have crossed the evening sky, and will be found at sunset on or near the eastern horizon. She will have made a half-revolution round the earth. After this she will continue to move east, and, of course, she will at dark be on the heavens below the eastern horizon.

95. It will be evident that she must have passed the point of the ecliptic 180° from the sun, since that point is always on the eastern horizon at sunset. When she crosses a celestial meridian running nearly north and south through this point, she is said to be in opposition with the sun. She may cross this line at any time of the day or night, but she does not move fast enough to get very far from it by the next sunset; and so, when she is at opposition, she will appear to rise in the east about the time the sun sets.

After opposition the moon can be seen only by sitting up until she rises, but her rising will come later and later, and finally it will be necessary to get out of bed before light in the morning in order to see her. After her opposition, she approaches the sun on his western side, and she can finally be found in the morning near him. Twenty-nine and a half days after opposition, she would pass the sun, and after that she would again be seen in the west as new moon. Thus, continued ob-

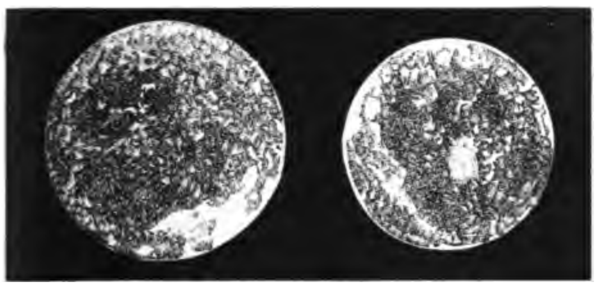
* See Introduction, "How to Learn and Teach the Constellations."

* The student can readily understand the position of these bodies in nature, and therefore a diagram is quite unnecessary. It is usually positively pernicious, since students think of the diagram rather than the positions in nature. They may have their heads filled with diagrams corresponding to nothing whatever in nature that they know.

servation shows us plainly that the moon's proper motion is a revolution round the earth as a center.

96. **The Moon's Orbit.**—During this revolution the moon would not have changed apparent size, so far as the observer could tell without measurement. Therefore it would be evident that the figure of her motion was nearly a circle with the earth as a center.* Measurement, however, shows a change; and for this and other reasons it is believed that the figure of her orbit is an ellipse. The drawings (Fig. 21) show the variation in the moon's apparent size.

FIG. 21.



When the moon is near the horizon, she looks larger than when she is seen overhead; but this is an illusion, as is shown by measurement. We estimate her distance from us by so many intervening objects, that she seems to us farther off, and therefore larger.

97. **Sidereal and Synodical Revolutions.** — At conjunction, or new moon, at the beginning of these observations, the moon would be very near the sun; and, as the student knows, a constellation of the zodiac would be behind, or west of both. Thus the earth, moon, sun, and a star-group would be nearly in line. After the moon had completed its revolution of twenty-nine and a half days, and was again in conjunction with the sun, and on the western horizon at sunset, the same star-group would not be there, but another, since the stars would have been moving west all the time. The star-group which was on the horizon at the first conjunction would have gone below the horizon, and the earth and the moon would have been in line with the first star-group before the moon came in line with the earth and sun.

The interval of time after which the moon comes back to the line between the earth and the first star-group is called a Sidereal Revolution of the moon. The interval after which the moon comes back to the same position with regard to the earth and sun is called a Synodical Revolution of the moon. Thus the period between two successive conjunctions or two successive oppositions is a synodical revolution. A sidereal revolution is completed in twenty-seven and one-third days, and a synodical revolution in twenty-nine and a half days.

* That the moon's orbit is nearly a circle, follows from this, and the fact that her path on the heavens is a circle.

98. If the student were asked why the sidereal revolution is shorter than the synodical revolution, he would perhaps say, "Because the stars move west." But the motion of the stars is apparent, and due to the earth's annual eastern motion round the sun. Therefore astronomers say that, when the moon has come round to the stars from which she started, she has to go a little farther to catch up with the earth and revolve round the sun.

II. The Moon's Path and the Ecliptic.

99. The second line of observation is to watch the moon's path among the stars, and learn how it is situated in regard to the ecliptic. The moon is nearer to us than any heavenly body, while the fixed stars are at an immeasurable distance, but she seems to move among them, because they are on the background of the sphere against which we see her.

Sometimes the moon's light obscures the stars near her, so that it is somewhat difficult to trace her path with any certainty. But even in this case the student must learn all he can from observation, and must not stop because he can not see everything.

100. The points to be noted in watching the moon and the ecliptic are as follows: The student must note that the moon is always in a zodiacal constellation, and always very near the ecliptic. She sometimes seems to move toward it, sometimes from it. She crosses it. It is somewhat difficult to ascertain the exact point of crossing, but the almanac gives help. The symbols "◐ in ☊" signify "The moon to day crosses the ecliptic going north." The symbols "◐ in ☋" signify "The moon to day crosses the ecliptic going south."

101. The paths of the sun and moon intersect at an angle of 5°. Therefore she is always very near the circle of the ecliptic, and when at conjunction she passes the sun, she can never be far north or south of the line passing through sun and earth; and, if she is crossing the ecliptic at the time, she will be on it. Also, at opposition, she can not be very far north or south of the line joining earth and sun, since that line passes through the point of the ecliptic 180° from the sun. She will be on it if she is on the ecliptic.

102. The points where the path of the moon crosses the plane of the ecliptic are called Nodes.

III. The Moon's Phases.

103. This is the third subject to be studied by the observation of nature, beginning at new moon. Fig.

Fig. 22.

1 2 3 4 5

22 represents the phases of the moon from new to full; and, reversing the order, from full to new again.

First Quarter.—If we begin to observe the new moon as soon as she is seen in the west, she will have the appearance of 1 in Fig. 22, viz., a full circle covered with a faint illumination, but having around the margin, turned toward the sun below the horizon, a slender bright crescent. If we suppose that the moon shines by the light of the sun which she reflects to us, and that the sun is a great deal farther from us than the moon, it will account for the appearances. The sun must enlighten half the moon, and half the moon must be turned to us; but these must be nearly opposite halves, since the moon is nearly between the sun and earth. But since the moon is not on a straight line between the earth and sun, but a little above the line, it is clear the halves turned to us and to the sun can not be exactly opposite halves, but must coincide a little. We see the bright crescent because we see a small part of the half that is enlightened by the sun.

But the hemisphere of the moon turned toward the earth just at dark is turned toward the portion of the earth just below the western horizon, which is bathed in sunshine. As moonlight causes a faint illumination on the earth, it is clear that sunlight reflected from the earth to the moon could cause the faint light seen over the moon's whole surface.

Second Quarter.—If we continue to observe the moon, we shall see that, as she moves east, she rises higher, and the crescent increases; and at seven days after new moon she is overhead at sunset and is a half moon. She has then passed her first quarter, as it is called, and begins the second. In this case, her western side is still turned toward the sun; but, since she is above our heads at sunset, only half the western hemisphere coincides with the hemisphere which we see above us. For this reason we find only a half-hemisphere enlightened or visible, and the convex side of that is turned toward the west.

Third Quarter.—After this, as the moon continues to move east, she increases in size, and about fifteen days after new moon she begins her third quarter. She is then full, or shows a full enlightened circle; and she is rising in the east while the sun is setting in the west. The same side is now turned toward us and toward the sun, for she is now nearly in line with sun and earth, the earth being in the middle. If she were quite in line, it is evident that the earth would cut off the sun's light from her, and we should have an eclipse of the moon. If at full moon she is in that part of her path on the heavens which crosses the ecliptic, she is in a direct line with earth and sun.

At full moon she is 180° from the sun on the celestial sphere; and, as she still moves east, she must approach the sun on the other side, and so she begins to decrease on her western side. After the beginning of her third quarter, she can generally be seen in the daytime, because she is so far from the sun on the sphere that he does not entirely obscure her light. When, from approaching the sun, she becomes invisible in the daytime, she can best be observed by rising just before light in the morning. We know that, at that hour, the sun is just below the eastern horizon.

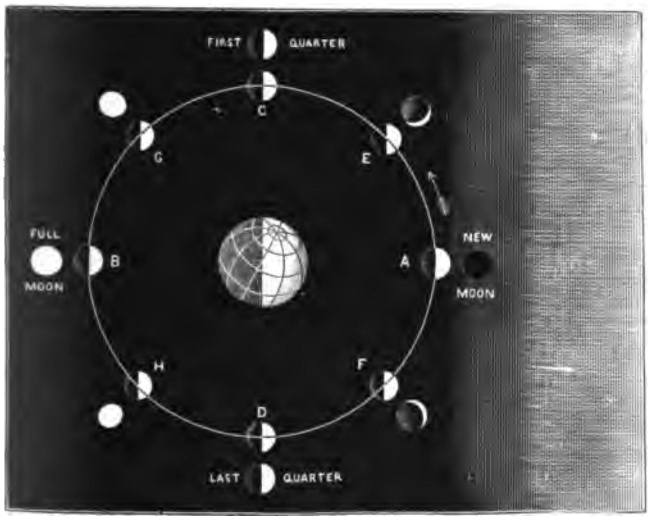
Fourth Quarter.—About twenty-one days after new moon, she begins her fourth quarter. She is then a half-moon again, and when seen while it is still dark in the morning, she is nearly overhead, with her convex side turned toward the sun. It is evident that he illuminates her eastern hemisphere, and that we see only half of it. The half-hemisphere which we do see has its convex side turned east.

After this, we should find the moon drawing nearer the sun at sunrise, and about the twenty-seventh day after new moon we should again see the faintly illumined full circle with the bright, slender crescent on the side next the sun. Sun and earth would again face opposite sides of the moon, nearly, but not exactly. The moon being a little above the line between earth and sun, the hemisphere opposite each would to a very small extent coincide; and this is the reason why we should see the crescent. The faint illumination would be turned toward the sunny side of the earth below the eastern hori-

zon. Finally, the moon would pass nearly between earth and sun, and then we should have new moon again. If the moon passed directly between earth and sun, it is clear she would intercept the sun's light from us, and we should have an eclipse of the sun. There is no eclipse unless moon and sun are together at the points where the moon's path on the heavens crosses the ecliptic.

The moon's phases are sometimes illustrated by a diagram which is given below (Fig. 23), mainly because some teachers will like to have it. The knowledge which

FIG. 23.



The Phases of the Moon.

such a diagram seems to give is very delusive. The student will be very unwise not to watch the moon herself.

From observing the moon it is very clear that she shines by light reflected from the sun, for we do not see any illumination except on the parts which are turned toward the sun.

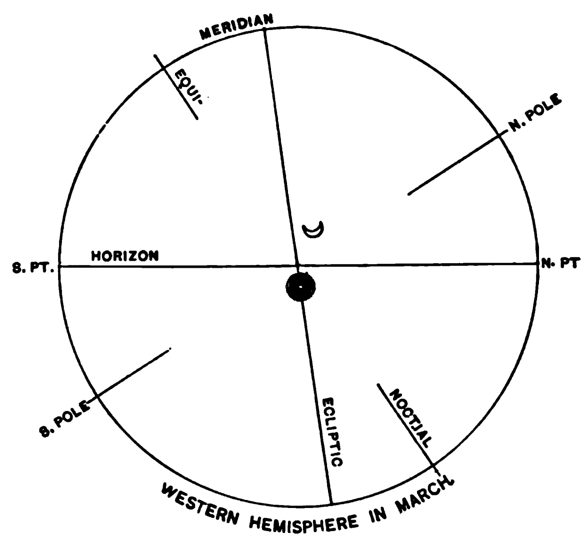
104. Nothing can give a student of astronomy a complete idea of the causes and conditions of eclipses but observation of the relative positions of sun, moon, and earth through a full synodical revolution. He will see that sun, moon, and earth never are nearly in line except at new and full moons; that at new moon only, they are nearly in line with the moon in the middle; and therefore an eclipse of the sun can take place at new moon alone. Also, at full moon only, they are nearly in line with the earth in the middle, and therefore an eclipse of the moon can take place at full moon alone. He will see that they never can be in line unless the moon at full or new is on the ecliptic; that is, unless the earth and moon are on the line in which the planes of their orbits intersect.

The subject of eclipses will be more fully treated further on.

105. Positions of the Moon's Crescent.—From new to full, the moon increases gradually from a crescent to a full circle, and back again from full to new; but, owing to the fact that the moon is sometimes north of the ecliptic, sometimes south of it—that is, sometimes north of the sun's path, and sometimes south of it—the positions of the crescent vary. The variation is most noticed at new moon, when the sun is known to be just below the horizon. Sometimes a line joining the horns is nearly vertical, as ◐; sometimes it is nearly horizontal, as ◒. Superstitious people call the first "wet moon," and the last "dry moon," and suppose they foretell the weather. The variation really depends on the positions of the moon and sun in regard to the horizon.

The moon's crescent may have any position intermediate between these. It is most nearly horizontal at the new moon near March 21st, and most nearly perpendicular at the new moon near September 21st. At sunset on March 21st the ecliptic has nearly the aspect of Map I. Fig. 24 shows the western hemisphere of the heavens at this time, and it shows that the ecliptic is

FIG. 24.

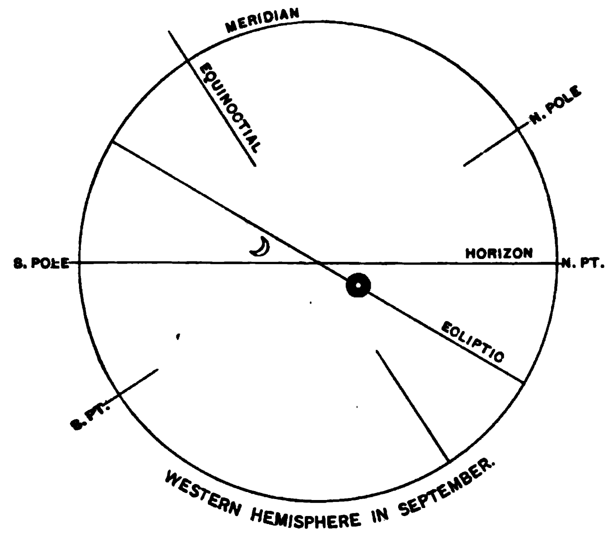


nearly perpendicular to the horizon. In this case, the sun, which is always on the ecliptic, is nearly below the intersection of ecliptic and horizon. If the moon is at the same time north of the ecliptic, she is directly over the sun, and as the convex side of the crescent is always turned toward the sun, it is nearly horizontal.

On September 21st, at sunset, the ecliptic has the aspect of that circle on Map II. Fig. 25 shows the western hemisphere of the heavens at sunset on September 21st, and it is seen that the ecliptic is much inclined to

the horizon. The sun, after setting, is far north of the intersection of ecliptic and horizon. If the moon at this time is south of the ecliptic, she is nearly south of the sun, and therefore the line joining the horns of the crescent is nearly vertical.

FIG. 25.



The facts which explain these positions of the crescent are: 1. The position of the moon in relation to the ecliptic. 2. The two positions of the ecliptic in relation to the horizon. These facts will have little reality to the student unless he sees them in nature. But in order to give them reality, it is not necessary for him to wait and see them with the new moon.

106. The Moon's Axial Rotation.—The most careless person usually remembers, without special observation, that the moon always presents the same shadings of surface, in which many persons have traced a resemblance to a man's face. Thus it is evident that we must see nearly the same hemisphere of the moon all the time. If the student will walk around a chair with his face turned to it all the time, he will imitate the motion. In doing this he turns his face once to every point of the compass. This is precisely what he does when he stands on one spot and turns round or revolves axially. Therefore the moon's motion is usually described by saying that she revolves once on her axis while performing her revolution in her orbit.

107. The Moon's Librations.—At different times we really see a little more than one half the moon's surface. The motions to which this is due are called the moon's Librations. In consequence of the elliptical form of the moon's orbit, her motion, like that of the earth, is unequal. But her motion on her axis is equal, and therefore her orbital motion sometimes gets ahead of her axial motion, or falls behind it, and thus we see a little farther around her east or west. This is called her Libration in Longitude.

The moon's axis, like that of the earth, is inclined to the plane of her orbit, and, like the earth's axis, always moves parallel to itself. We know this, because, when we see the moon through a telescope, she shows a change in the part round the poles. This is called the moon's Libration in Latitude.

Owing to the fact that we are about four thousand miles from the center of the earth, which is the center of the moon's motion, we see her from slightly different positions when on our eastern and western horizons; and there is thus a slight variation in the part of the surface seen. This is called her Parallactic Libration. Parallax is the displacement of an object caused by the observer's change of position.

We see in all about .58 of the moon's surface.

108. Times of the Moon's Risings.—What we call the moon's rising is due to the earth's rotation on her axis, carrying the horizon east to meet her. But during one rotation of the earth the moon moves 13° east in her orbit, and therefore the horizon must move farther to overtake her. As the earth and horizon revolve through 1° in four minutes, it takes fifty minutes, on an average, for the horizon to catch up with the moon. Therefore she rises about fifty minutes later every day. But the times of the moon's rising vary a good deal.

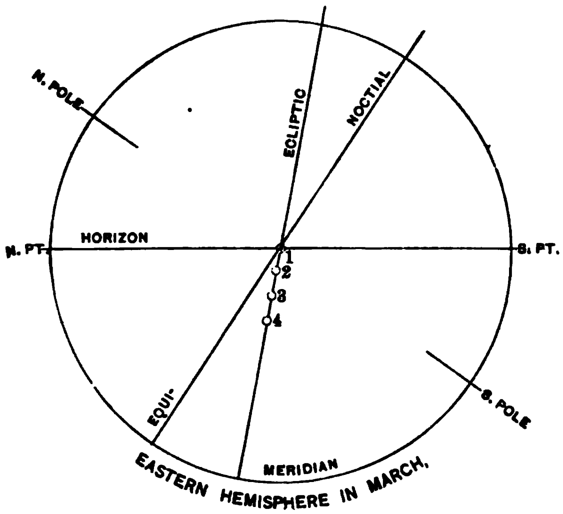
109. Harvest Moon.—When the constellation Pisces is on the eastern horizon at the time the moon rises, the retardation in her rising on successive nights is much lessened. In latitude 40° the delay may be only about twenty-five minutes. The difference is the more noticed when the moon is full, both because she is then more conspicuous, and because she rises at a more convenient hour for observation. The full moon rises in Pisces within a fortnight of the autumnal equinox in September. It is widely noticed by farmers, to whom its early risings are of use in gathering the crops. They call it Harvest Moon.

When Virgo is on the eastern horizon at full moon, which happens within a fortnight of the vernal equinox in March, the delay in her rising is increased. In latitude 40° the difference in her time of rising on successive nights may equal an hour and a quarter.

An explanation (and diagrams) of these phenomena are of little use except to aid the student in observing the facts in nature which cause them. A knowledge of mere diagrams is illusory. In order to have real knowledge, however, it is not necessary to see all the facts together, and therefore not necessary to wait until harvest moon. The facts are as follows: 1. The moon is

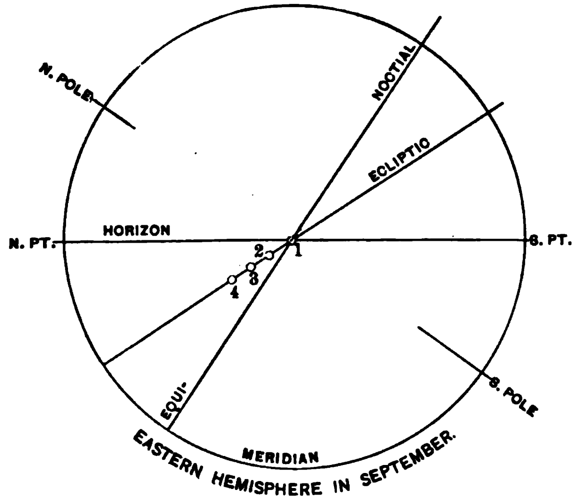
always very near the ecliptic, and we can therefore use the ecliptic to illustrate the angle which her path among the stars makes with the horizon. 2. The moon moves east among the stars; this causes the delay in her ris-

FIG. 26.



ing. 3. In March the ecliptic (and the moon's path) seem to curve very little toward the south, and she therefore moves on a path nearly perpendicular to the horizon. Map I shows this, and so does also Fig. 26, exhibiting the eastern hemisphere of the heavens and the aspect of the ecliptic in March. Also, in September, the ecliptic is much inclined to the horizon. This is shown in Map II and in Fig. 27, exhibiting the eastern hemisphere of the heavens for September, with the aspect of the ecliptic. It is clear that it would take longer to overtake the moon

FIG. 27.



moving away from the horizon on a path like the ecliptic of Fig. 26, than when she moves on a path like the ecliptic of Fig. 27, even if she moved 13° daily on both. And as her rising is due to the horizon moving down to overtake her, she is less delayed in rising on successive nights in September; and in March the delay is greater. In December and June, the path of the ecliptic is nearly parallel with the equinoctial, and the angle of the equinoctial and the horizon does not vary at all, as can be seen from Figs. 26 and 27.

Since the ecliptic is not a visible line in nature, it can not be traced so definitely as on the diagram; but a careful observer, tracing it by the stars, and noting the direction of the zodiacal constellations, will have no difficulty in seeing the difference in the angle, as exhibited in March and September.

Harvest moon has these peculiarities only in high latitudes, because the great variation in the angles is due to the elevation of the pole above the horizon. The elevation of the pole makes all circles running east and west (or nearly east and west) curve southward at and near the point where they cross the meridian above us. A consideration of Figs. 26 and 27 will show that the difference in the angles with the horizon is due to the elevation of the pole above the horizon.

110. **The Moon's Motion North and South.**—Since the moon's path on the heavens is so near the ecliptic, she must vary in position north and south. Also, since she goes through 180° in about fifteen days, she must move from north to south much faster than the sun. This can be seen plainly by watching her risings and settings on successive evenings. Since full moons are always 180° from the sun, they are far north in winter, and longer above the horizon than in summer, when they are far south. Thus they illumine the long winter nights when they are most needed.

111. **Revolution of the Nodes.**—Let us suppose that the student, watching the moon, sees her approaching the ecliptic, and, aided by the entries of the almanac, "◐ in ☊," and "◐ in ☋," identifies with some degree of accuracy a point where she crosses the ecliptic. If, a year or eighteen months afterward, he observes the moon at the same crossing, he will find that she crosses earlier, or farther west. Of course, the intersections, moving on a circle, will finally come round to the point from which they started. Now the moon seems to cross the ecliptic on the heavens, only because she is then crossing the *plane* of the ecliptic. Thus this revolution shows that the moon's nodes revolve on her orbit. It is completed in about nineteen years.

Eclipses.

112. **Umbra and Penumbra.**—When a luminous body is larger than a point, the shadows made by intercepting

its light consist of two portions. There is a dark central part which receives no direct rays from the luminary. This is called the Umbra. Surrounding the umbra, there is a fringe of less dense shadow, which receives direct rays from some portions of the luminous body, but not from all portions. This is called the Penumbra.

113. Shadows of Earth and Moon.—The shadows formed by intercepting the sun's light consist of an umbra and a penumbra. The umbra belonging to the shadow of the earth or moon is cone-shaped, with the apex of the cone turned away from the sun. The penumbra increases in width with the distance from the sun (see Fig. 28).

114. Eclipses of the Moon.—An eclipse of the moon takes place whenever the moon passes through the umbra of the earth's shadow. So small an obscuration results from the moon's passage through the penumbra, that it is not called an eclipse. In a total eclipse of the moon her whole sphere is still faintly visible, and is of a coppery hue. This is due to rays of light refracted by the earth's atmosphere, so as to fall on the moon.

Fig. 28.

Explanation of Solar and Lunar Eclipses.

115. Eclipses of the Sun.—A total solar eclipse takes place in any part of the earth which is in the umbra of the moon's shadow. The umbra of the moon's shadow is so small that it does not often cause darkness over a part of the earth's surface more than a hundred miles in diameter, but by the earth's rapid rotation, this shadow is carried forward over a long zone or band of territory about a hundred miles in width. A total solar eclipse is a very striking event. The stars come out and the animals go to rest. A total eclipse of the sun is an interesting event to astronomers, because it gives them an opportunity of studying the sun's corona, of which an account will be given in the chapter on "The Sun."

A partial solar eclipse exists in those parts of the earth which are in the penumbra of the moon's shadow.

The moon's distance from the earth varies, on account of the elliptical form of her orbit. If an eclipse of the sun occurs when the moon is at her greatest distance from the earth, her apparent diameter is diminished, and she can not entirely hide the sun from us. We have then what is called an Annular Eclipse of the Sun. The moon conceals the central part of the sun's surface, but around her dark body is seen a ring of brilliant light.

A total eclipse of the sun lasts but a few minutes, and often only a few seconds. A partial eclipse lasts several hours. A lunar eclipse may be total for two hours, during which time the moon is crossing the umbra of the earth's shadow.

116. Frequency of Eclipses.—Solar eclipses are more frequent than lunar eclipses. The reason can be seen by examining Fig. 28. In a lunar eclipse the moon crosses the cone of the earth's umbra. In a solar eclipse she crosses a prolongation of the same cone toward the sun, which is equal to a broader part of the cone. But in any one place there are more lunar than solar eclipses, because a lunar eclipse is seen wherever the moon is visible, while a solar eclipse is visible over a small territory. A total or annular eclipse of the sun is, in any one place, an event of very rare occurrence. There has been no total solar eclipse in London since 1715, and there was none for more than five hundred years before that date.

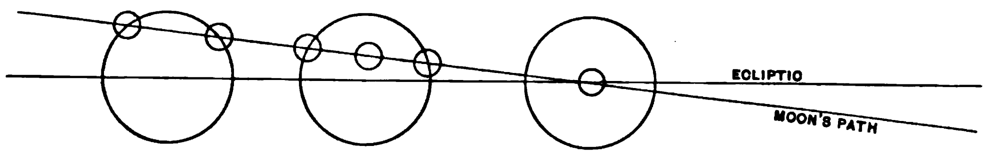
117. Causes of Eclipses.—Whenever the sun or moon is eclipsed, some parts of the sun, moon, and earth must be in line. It is evident they can not be in line, with the moon in the middle, except at conjunction, and therefore a solar eclipse must take place at the passage of the moon from old to new. The sun, moon, and earth can not be in line, with the earth in the middle, except at opposition, and therefore a lunar eclipse must take place at full moon.

But opposition and conjunction do not always bring eclipses. The reason is evident: the moon is not always at the intersection of her orbit with the ecliptic when she is at conjunction or opposition.

The moon passes the nodes, or, in other words, crosses the ecliptic, during every revolution round the earth; and yet there is not always an eclipse. But the reason of this is also plain: the sun and earth are not always in line with a node when she passes it.

The moon's path on the heavens crosses the ecliptic at an angle of 5°. In other words, the plane of her orbit and the plane of the earth's orbit intersect at an angle of 5°. It is evident, from Fig. 29, that some parts of the earth and moon may be in line, though not their centers, both just before and just after she passes a node.

FIG. 29.



A line joining the points where the moon's path on the heavens crosses the ecliptic, passes through the nodes of the moon's orbit. When the earth and sun cross that line, twice a year, they "pass the nodes." Students generally understand the circumstances of eclipses better by studying a few records of eclipses from almanacs of successive years:

1882.—May 17th, solar eclipse; November 11th, solar eclipse.

1883.—April 22d, lunar eclipse; May 6th, solar eclipse; October 15th–16th, lunar eclipse; October 30th, solar eclipse.

1884.—March 27th, solar eclipse; April 10th, lunar eclipse; April 25th, solar eclipse; October 4th, lunar eclipse; October 18th, solar eclipse.

1885.—March 16th, solar eclipse; March 30th, lunar eclipse; September 8th, solar eclipse; September 23d, lunar eclipse.

From these records the student sees there are two eclipse periods in every year—evidently at the passage of the nodes by the earth and sun. These periods come earlier every year, a result plainly due to the backward movement of the nodes on the ecliptic. The record of 1883 can be explained by remembering that the earth and sun move very slowly from the node, while the moon crosses the heavens in a little less than fifteen days. In 1883 the earth remained at the nodes long enough for the moon to be eclipsed and then cross the heavens to eclipse the sun fourteen or fifteen days afterward. The record of 1884 shows that the moon may partially eclipse the sun on one side, cross the heavens to be eclipsed herself fourteen days afterward, and then cross back to eclipse the sun twenty-nine days afterward.

The student will not be surprised to learn that the slow motion of the sun and earth, together with the rapid motion of the moon, renders it impossible for the two former bodies to pass the moon's nodes without an eclipse.

From the record of 1882 it is clear that there is a period of less than six months between two passages of the nodes by the sun and earth. Therefore, if this event takes place just at the beginning of the year, they will pass again in less than six months, and will thus reach the beginning of the third eclipse period within the year. When there are seven eclipses in a year, four must be eclipses of the sun. If there are but two, both are eclipses of the sun. There can not be more than seven or fewer than two.

A further account of the moon will be given in the General Account of the Solar System, Part II.

CHAPTER VI.

THE PLANETS AND THEIR MOTIONS, AND HOW TO OBSERVE THEM.

118. The planets are stars which, like the earth, revolve round the sun as a center. Five of these bodies, Mercury, Venus, Mars, Jupiter, Saturn, can be seen without a telescope; and the first four are so often in the sky above us just after dark, that there is no difficulty in knowing them by sight, and in seeing and understanding their motions.

It is the object of this chapter to give such an intelligible account of these movements, in the order in which an observer will see them, that any sensible student may use it to gain what will be a life-long pleasure and advantage, viz., the power to look at the changes in the heavens with intelligent recognition.

119. The Superior Planets.—For reasons which will be made clear a little further on, the planets are divided into two classes, called Superior and Inferior Planets. Jupiter, Saturn, and Mars are the superior planets which can be seen with the unaided eye.

120. How to find Jupiter, Mars, or Saturn.—Except when they are very near the sun, Jupiter, Mars, and Saturn can be seen at some hour of every clear night. The student's knowledge of them will probably be chiefly gained by watching them in the evening before bedtime, and it is well to form a habit of observing them at dark. These planets come into the sky from the east. It will give reality to the study of them if the student who begins this chapter will get a good almanac, and find where they are then, or when they will become evening stars. Three steps are to be taken: 1. To find out when they are evening stars. 2. The student must

know where in the heavens to look for them. 3. He must understand how they can certainly be known when seen. A few words will be said on each subject:

121. I. How to tell when a Planet is in the Evening Sky.—They come in at opposition, they go out at conjunction. The dates of the oppositions of Jupiter, Mars, and Saturn are given in any good astronomical almanac under the following symbols; ☍ means opposition; ☉, the sun; ☍ ♃ ☉, opposition of Jupiter with the sun; ☍ ♄ ☉, opposition of Saturn with the sun; ☍ ♂ ☉, opposition of Mars with the sun.

The publishers of this book will send out with every copy sold a printed slip containing any oppositions coming within three years from the current year. The oppositions of Saturn come once in about a year; those of Jupiter, every thirteen months; those of Mars, every twenty-six months. About two months before opposition, a superior planet can be seen in the evening as early as ten o'clock. For this reason it is best to begin observation about two months before opposition. The planets are not called "evening stars" until they rise at sunset; and they are called "morning stars" from the time that they rise with the sun. The best almanacs give the times of risings of the planets.

122. II. In what Part of the Sky must these Planets be looked for?—They are always found in the zodiacal constellations, and very near the ecliptic. They are never more than $2\frac{1}{2}°$ from the ecliptic. The student who knows the constellations of the zodiac, can tell almost at a glance whether Saturn, Jupiter, or Mars is visible. A star of the first magnitude seen where one was never seen before, by a person familiar with the ecliptic, is sure to be a planet. Intelligent acquaintance with the heavens is not possible without the knowledge of the ecliptic. In the introduction to this book, "Directions how to learn and teach the Constellations," will be found careful directions for learning the ecliptic. All the zodiacal constellations visible at one time can be learned in a few evenings.

It is perhaps well to add a few words about each superior planet, and to say that they can be most easily identified at and near opposition, both because they are then brightest, and because we know we must look for them at dark not far from the eastern horizon. Jupiter can be recognized at any time of night when he is known to be above the horizon, because he will be the brightest star visible unless Venus is present; and he can easily be distinguished from her by the test of planetary motion, which will presently be explained under III.

Near opposition, Mars will be as bright as any star in the east except Jupiter. It is easy to know whether Jupiter is in the sky, and then Mars can be distinguished by his red color. Mars varies in luster more than any of the three, and could hardly be identified by an inexperienced observer when he is more than eight months from opposition.

Saturn varies less than any of the three. An observer must find him chiefly by knowing the zodiacal stars near the ecliptic, and thus recognizing a stranger among them. He is about as bright as the brighter first-magnitude stars.

123. III. How the Planets can certainly be known when seen.—When the observer thinks he has found a planet, or wishes to distinguish between two or three stars, one of which he supposes to be some planet, he can make perfectly sure by the test of planetary motion now to be described. The stars are divided into planets and fixed stars. The fixed stars can never be seen to approach or recede from one another except by trained observers using instruments of the most delicate and extreme accuracy.* For this reason the constellations keep the same figures, coming and going as if painted on a rolling panorama. But the planets recede from one star and approach another. Our study of them consists chiefly in watching this motion. It can not be done without care and patience, but, when the student gets fairly at it, it becomes very interesting work.

When the student first sees a planet, or a star supposed to be one, he notes very carefully its position in regard to fixed stars near it. Very often it will be found in line with two other stars, as seen in Fig. 30.

In this case any movement will at once be indicated by the planet being out of the line (breaking line), unless the line is nearly parallel with the ecliptic. Sometimes it forms regular figures, as triangles, right or isosceles, and then movement shows

FIG. 30.

itself very soon by the alteration of the figure. The motion of Mars can usually be detected in forty-eight hours; that of Jupiter in a week or less. Jupiter and Venus can be readily distinguished from one another by the rapidity of the movement of the latter, which becomes evident after an interval of twenty-four hours. Saturn moves more slowly than any of the planets seen with the unaided eye; but the movement can always be detected when his position in relation to other stars is well observed.

All this observation requires perseverance, but the student should be encouraged by knowing that it affords valuable training for a faculty much neglected in our schools, viz., the power of intelligent observation. As fast as a planet moves out of one figure that he has discovered, he seeks to find another. He notes the direction of the motion, and whether the planet is north or south of the ecliptic. A star which does not move among the stars can not be a planet.

124. Motions and Appearances of Superior Planets.—There are two important motions which are the key to our knowledge of a superior planet. They are called the Synodical Revolution and the Sidereal Revolution.

125. The Synodical Revolution.—Let us suppose the observer begins at the planet's opposition with the sun. It will be found at dark just above the eastern horizon; and, as the sun is known to be just below the western

* The trained observers have detected the motion of only a few.

horizon, the planet is seen to be opposite the sun. If it is on the ecliptic, it is in a straight line with earth and sun; but since it is always on or very near the ecliptic, it is always very nearly in line at opposition.

Since the planets, like all other heavenly bodies, have an apparent diurnal revolution owing to the earth's rotation upon her axis, we must, to avoid confusion, watch the synodical revolution at the same hour of the evening. Some time about dark is most convenient.

The observer, beginning at dark, finds the planet then above the eastern horizon. If, after an interval of three or four weeks, he observes the planet at the same hour, he will find it, like the constellations of fixed stars, situated farther from the eastern horizon and nearer the western. If, at intervals of two or three weeks during several months, he takes a look at dark, he will again and again find the planet, like the fixed stars, farther from the eastern horizon and nearer the western; and finally it would last be seen at dark just above the western horizon. The observer would have reason to think that after its disappearance it was on the western horizon with the sun at sunset; and, as it was always seen very near the ecliptic, it would be evident that it must at the same time be very nearly in line with earth and sun. This is the planet's conjunction with the sun.

If, after this, the student made observation just before day in the morning, the planet would be found just above the eastern horizon. If, during some months, it was occasionally observed at that hour, it would gradually be found farther and farther west, until it would finally be seen for the last time just above the western horizon. Then it would again be opposite the sun, or "in opposition" with him. It could again be seen at dark in the evening just above the eastern horizon. Between the two oppositions it would appear to have made a complete revolution westward around the earth. This revolution would have been so like the annual motion of the fixed stars, that the observer would suspect that it was also apparent, and due to the earth's annual motion around the sun.

But the fixed stars revolve round the earth in a year, crossing the evening or morning sky in six months, while Saturn would take a few days more than twelve months to complete his revolution; Jupiter would take thirteen months and Mars twenty-six.

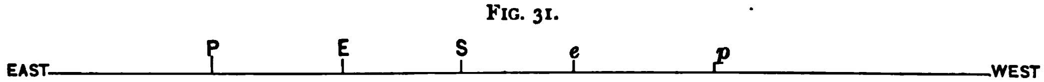
126. Real or Proper Motion.—The difference in the times of apparent revolutions of the planets and the fixed stars would be explained by the planet's motion among the stars, which the observer would have seen while watching the synodical revolution. It has already been noticed in 123. The planets move eastward among the stars. It will perhaps sound a little absurd to speak of a planet as having two motions, one of which is eastward and the other westward in direction. If the western motion were not apparent, it would be absurd. The student can form an idea how the two motions appear to go on together, by imagining the celestial sphere revolving and carrying the planet west, while the planet at the same time moves east on the sphere. Thus, a globe might revolve in one direction, and carry an ant with it, while the ant walked slowly round the globe in the contrary direction. We have reason to think the eastern motion of a planet among the stars a real motion, for the earth herself moves east, and so could not make the planet appear to move east.

Now the planet would, at opposition, be at a point among the stars, and when this point had in six months revolved to the western horizon, the planet would be at some distance east of it, and would thus be kept longer above the western horizon. Since Mars moves east among the stars faster than Jupiter, and Jupiter than Saturn, Mars would be detained longest in the evening or morning sky, and Jupiter would be delayed longer than Saturn.

The apparent western revolution of the superior planets round the earth is called a Synodical Revolution. This is usually defined as a period at the beginning and end of which a planet occupies the same position in regard to the earth and sun.

127. Variation in Apparent Size, and Definition of a Superior Planet.—If the planet supposed to be watched were Mars, our observer would see another fact very plainly. Mars evidently diminishes in apparent size when crossing the evening sky, and increases while crossing the morning sky. Jupiter and Saturn also vary through the same period, but the change is not so marked.

FIG. 31.



Let us suppose that the line above (see Fig. 31) represents that drawn from east to west through earth and sun at sunset.

S is the sun's place; E, the earth's place; and *e*, the point of the earth's orbit lying west of the sun. At opposition the planet was east of the observer at sunset. As he was evidently farther from the sun then than the earth was, we mark his position at P. For the same reason we put the mark *p* for his position in the west at conjunction, beyond the sun and also beyond the point of the earth's orbit. Now, if the planet was at the point marked *p*, it explains why he decreased in apparent size.

While P and p are at the same distance from the sun, they are at very unequal distances from the earth at E. When the planet is at P, the observer at E is on the side of the earth's orbit nearest him; but when he is at p, the observer at E is on the side of the earth's orbit most distant from him. From E to e is a diameter of the earth's orbit, a line more than 184,000,000 miles long. Therefore, Mars appears larger when seen at P than at p, because he is more than 184,000,000 miles nearer. Thus this increase of the superior planets in apparent size confirms the belief that they are at all times farther from the sun than the earth is. This is what we mean by a superior planet. It is always at a greater distance from the sun than the earth is. At opposition the planet and earth are in line with each other and the sun, on the same side of the sun; at conjunction, on opposite sides.

The student must use this line to get the positions in nature, as he can see them. He should make sure of this by pointing to them. The diagram is useless except for this purpose.

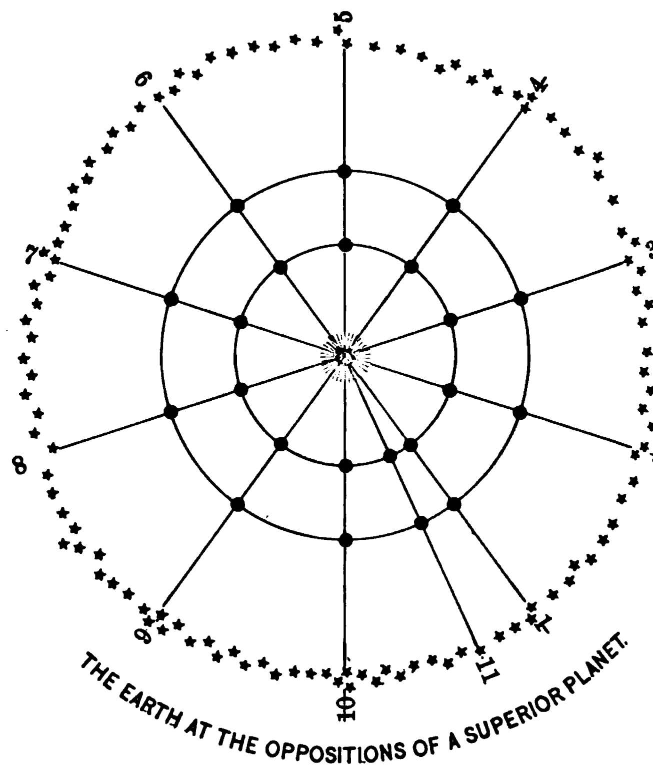
The fact that Jupiter varies less than Mars in apparent size, and Saturn less than Jupiter, can be accounted for by supposing that the two latter are so very far from earth and sun that an approach of 184,000,000 miles nearer is comparatively small.

128. The Sidereal Revolution.—A planet always lies in a straight line between the sun and some star-group, since stars are all round the sun; but at the opposition of a planet we can know the star-group, for we are ourselves in line between it and the sun. At dark a line from the sun, which is just below the western horizon, through the earth, reaches an ecliptic point just above the eastern horizon, and at opposition the planet is seen at dark very near it. We can see that he is in the same direction from us that we are from the sun at sunset. If we sit up till midnight we see an ecliptic point on the meridian, and the planet at opposition is very near it. The four or five stars nearest the planet and this point are a group. As we are between this ecliptic point and the sun, we are between the sun and this group. So is the planet, though he seems to be among the group, but we know this is the effect of projection. So we can be quite sure the planet is in line between the sun and this group. If we are not quite in line with the sun and planet, we are between the sun and the same star-group.

After a year's time the same star-group would be above the eastern horizon at dark, and we should again be between the sun and this group, but the planet would not be there. He would have moved east and would be below the horizon. But after a while he would again be above the eastern horizon at dark, and, of course, opposite the sun. He would be between the sun and a second star-group. We should know it, for we also should be between the sun and the same group. We should see the first and second group both lying on the evening sky, the ecliptic running through them, and the second group farthest east. Then, after a long interval, the planet would again be in opposition. We should see him between the sun and a third star-group. The three groups would lie on the evening sky along the ecliptic, the last one being farthest east. The two intervals between the three would be about equal. After a number of oppositions, there would be a chain of these groups, at equal intervals, extending entirely across the evening sky and along the ecliptic; and we should know that our planet had been between the sun and every one, for we should have been there at the same time. After a still longer time, the star-groups would make a ring round the whole heavens, both above and below the horizon. We should know that the planet had been between the sun and every one. As they would evidently lie in a ring all round the sun, it would be evident that the planet had made a complete revolution round the sun (see Fig. 32).

Now, unless the annual motion of the stars is real—

FIG. 32.



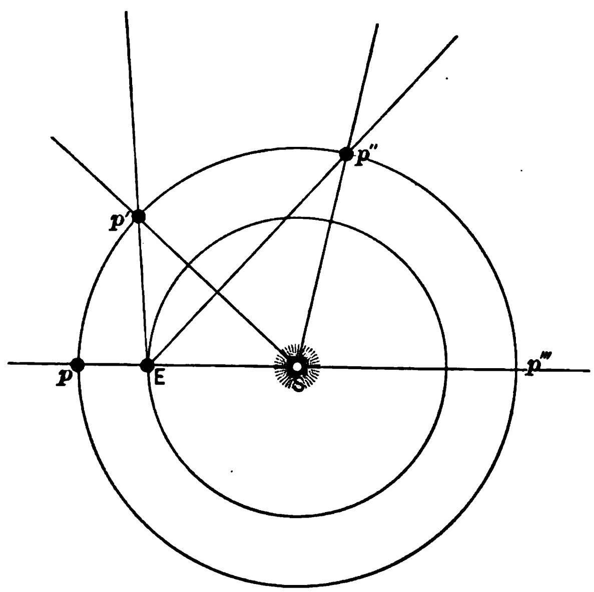
unless the earth is at rest, and the sun and stars are in motion—it is clear our supposed planet revolves around the sun. This revolution of a planet from one star-group

back to the same is called the planet's Sidereal Revolution.

129. It would take Jupiter nearly twelve years to make a sidereal revolution, and it would take Saturn nearly thirty. But the case is quite different with Mars. His motion among the stars is very rapid, and between two successive oppositions he would be seen moving rapidly east through many zodiacal constellations. But when the second came, he would be only 48° in advance of his first position. It is a reasonable conclusion that Mars makes a full sidereal revolution, and goes 48° beyond, while he makes one synodical revolution.

130. Times of Revolutions.—The student of geometry knows that we can not estimate circular or angular motion except from the center. But we are not at the center of the motions of the planets. Fig. 33, in which E represents the earth's position, and p, p', p'', p''', positions of a superior planet, shows that we could not see

FIG. 33.



the planet where it would be seen by an observer at the center, except when we are in line with it and the center. This is the position of sun, earth, and planet at conjunction and opposition. But we can not see the planet at all at conjunction. It is this that makes opposition so important a period in the study of a planet.

Now, when a sidereal revolution begins at an opposition, it does not end at one. We know the planet has completed its revolution because we see it at an opposition, in advance of the point from which it started. Therefore, we can not estimate the length of a sidereal revolution by counting days. But we can count the days of a synodical revolution, and measure the angular distance traveled. Since the synodical revolution depends on the motion of the earth and planet both, and neither moves through exactly equal spaces in equal times, both the days and distance vary a very little. But we can take the average, or mean, of many observations. Then the length of a sidereal revolution can be found by a question like the following: If the mean motion of Mars is 360°+48°, or 408°, in 779 days, how long will it take Mars to travel 360°? The answer, 687 days, is the period of the sidereal revolution of Mars.

131. Discussion of Appearances.—The apparent western revolution of the planets is much more conspicuous than their real eastern motion, because in the first case they move from east to west of *ourselves*. But the whole matter will be made clearer by considering the appearances produced by motion on earth. If we walk past an object at rest, it appears to move in a direction contrary to our own, and at last passes out of sight. But let us suppose ourselves walking on a straight road, and seeing in advance of us a person walking more slowly in the same direction. He seems to fall back, and we catch up and pass him, but he remains in sight longer than the object at rest. If he quickens his pace, still, however, walking more slowly than we do, he still appears to fall back, but more slowly, and he keeps longer in sight of us.

132. The fixed stars are objects at rest, and Mars, Saturn, and Jupiter are like persons walking in the same direction with ourselves, but at different degrees of speed, round a circle. When a planet and the earth come in line at opposition, it is because the earth, moving east faster, catches up with the planet and passes him. When they come in line at conjunction, it is because the earth has traveled 180° ahead of the planet, and is coming round the circle behind him, to catch up and pass him again. But the earth's motion is without jolt, jar, noise, or exertion on our part, and we do not feel that we are moving, so we take the appearance of the planet falling back to be the real motion.

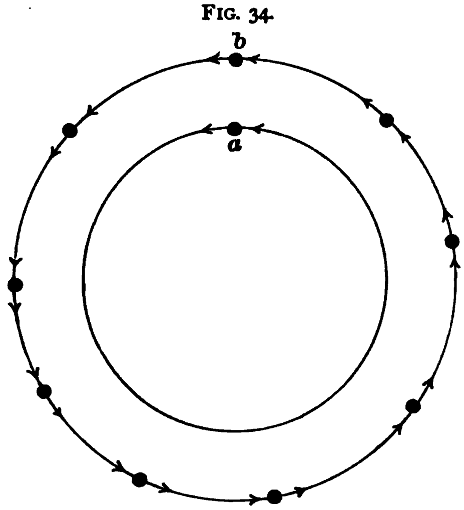
133. Apparent Retrograde Motion.—This is a very important apparent movement; but the description of it has been postponed in order to avoid confusion. Thus far all the facts and appearances can be explained almost equally well on the supposition that the earth is at rest, while sun, planets, and stars move round it with varying degrees of speed, as on the supposition that the sun is the center of motion around which earth and planets revolve. But it is otherwise with the interesting movement about to be described. It can be better explained on the theory of the earth's motion. This movement had great influence in making astronomers believe the

Copernican theory, by which the sun is supposed to be the center, and the planets to revolve round him.

134. For a few weeks before and after the opposition of a superior planet, it seems to move west among the stars instead of east. If we supposed that this motion was real, not apparent, we should see, by the advance east among the stars at opposition, that the planets must travel longer and farther east than west. But the movement is apparent, not real.

135. The student will best understand the cause of this apparent western or retrograde motion by an experiment. On ground, level and open, for fifty feet radius, he must draw two concentric circles with radii of about twelve and eighteen feet. He is to have an assistant who walks slowly around the outer circle, while he himself walks around the interior circle, a little faster, but in the same direction. At intervals he comes up in line with his assistant and the center, on the same side of the center (or on the same radius), and passes his assistant. While walking on all parts of the circle, he notes the passage of his assistant's head over the background. The apparent and real directions of the walker's motion on the outer circle are the same, until just before the two come in line (on the same radius), and then the observer sees his assistant's head retrograde over the background, or move in a direction contrary to that in which the observer knows he is really moving. The position of the three, when in line, is that of S, E, and *p*, in Fig. 33. This is just the position of the earth and a superior planet at opposition. They are in line on the same side of the sun.

FIG. 34.



There is nothing mysterious in this. When two walkers on straight paths walk with different degrees of speed in the same direction, the one in advance walking more slowly, and the one in the rear catching up and passing the other, the fast walker will see the body of the slow walker move over a distant enough background in a direction contrary to that in which he really walks. In the circles of Fig. 34, the arrows indicate the movement of revolution, and it can be seen that a mover at and near *a* is not moving in the same absolute direction with a mover on the outer circle, except when he is at or near *b*. The reason why the motion of the planet retrogrades near opposition only, is, the earth and planet are not moving in the same direction except at and near that time.

136. There is another point to be noticed. Jupiter retrogrades through a smaller angular distance than Mars, and Saturn than Jupiter. If the experiment with the circles is tried as before, except that the outer circle has a radius of twenty-five or thirty feet, it will be found that the walker on the outer circle retrogrades through a smaller angular distance than before.

137. To explain this retrograde motion, we must make one of two suppositions: 1. The earth moves round the sun in a figure nearly a circle, and, catching up in line with the superior planets, makes them seem to move backward, like the walker in the experiment with the circles. 2. The earth is really at rest, and the planets are in motion, but the planets, for no reason at all that we can conceive, imitate the movements they would appear to have if the earth moved.

It is clear that the first is the more reasonable supposition.

138. Several conclusions follow: 1. This motion of the planets toward the west is apparent. 2. Since the earth's motion gives the planets an apparent motion among the fixed stars, while the fixed stars themselves are too far away to change place among each other in consequence of the earth's motion, the planets must be a great deal nearer to us than the fixed stars. 3. Mars is nearer to us than Jupiter, and Jupiter than Saturn.

139. Summary of what the Student should observe.—The student will probably think that, if he must watch Jupiter twelve years and Saturn thirty, to become satisfied that they revolve round the sun, he will have to be contented with a blind acceptance of the statements of school-books.

In astronomy, as on other subjects, we accept the evidence of witnesses to fact. But on this, as on all scientific subjects, there is a great difference between a blind and an intelligent acceptance of testimony. We must know something of the nature of the facts, or we can not tell whether they are rightly interpreted. The motions here described consist largely of repetitions. But we can understand them perfectly, long before we go through with all the repetitions.

But the student who learns to look at the heavens with intelligence, will see a great deal more of the repetitions than he intends at first. The heavens are unrolled before us year by year, without any exertion on our part, and just at the time when we are most at leisure

We must shut our eyes, or look down, to keep from seeing them. Thus the person who learns to understand the changes in the heavens is apt to become an observer for life.

The following phenomena should be observed: 1. The positions of one or two of the planets in regard to earth and sun should be noted near conjunction and at opposition, and thoroughly understood. 2. The decrease in brilliancy from opposition to conjunction should be noted. This is best seen in the case of Mars. 3. The general eastward motion of all these three planets should be noticed; also, the western or retrograde motion among the stars near opposition should be noted. 4. The positions among the stars for two successive oppositions should be noted, in the case of Jupiter and Saturn especially. This shows the advance eastward. 5. The apparent motion toward the western horizon should be noted, and especially the period during which each planet is in the evening sky. 6. Besides this, the positions of the planets in regard to the ecliptic must be noted. But the student must clearly understand how much, how little, this proves. It shows with entire truth that the orbits of these planets are in planes very near the ecliptic. But it *does not show the exact planes in which they move.* As we are sometimes a little to one side of the planes in which they move, sometimes a little to the other side, we see them a very little displaced. But it is perfectly correct to say that they are always so near the ecliptic because they move in planes differing so little from that in which the earth moves. In no way can the student understand this so well as by watching their position in regard to the ecliptic.

The Inferior Planets.

140. Definition of an Inferior Planet.—Venus and Mercury are never seen near the point of the heavens opposite the sun. If they were not nearer the sun than the earth is, the earth would certainly come between them and the sun at some point of her revolution round that center. But we always see them not far from where we know the sun is situated. For this reason, and for others which will appear in studying them, they are supposed to move round the sun in orbits interior to the earth's orbit, and astronomers call them the "Inferior Planets." The student's knowledge of their motions must be chiefly gained from the study of Venus. Venus is very often so situated that we can observe her with the greatest convenience.

141. When and how to find Venus.—Venus is alternately evening and morning star for periods of 292 days each. She becomes evening star at what is called her superior * conjunction with the sun, and she becomes morning star at her inferior * conjunction with the sun. The symbol of Venus is ♀; that of conjunction, ☌; that of the sun, ⊙. The entries in the almanac are "☌ ♀ ⊙ superior" and "☌ ♀ ⊙ inferior." They are found at the proper dates. Besides these announcements, most almanacs have, in the beginning, another, giving the evening and morning stars for the year.

When Venus is known to be above the horizon in the evening, it is not possible to fail in identifying her, for she is found at dark in the west, and is far the brightest star visible. But the student will not be able to see her for some time after conjunction. The delay depends on the angle made by the path of Venus with the horizon, and on the clearness of the weather. She should be looked for three weeks after conjunction, and after that once a week, at least, until she is found.

If the student prosecutes diligent search, she will be seen at first so early after sunset that no other stars will then be visible. The observer should note and remember the point of the horizon above which he first sees her.

142. Diurnal Revolution. — On the evening when Venus is first seen she will set in the west just as the new moon does. As all the other heavenly bodies do this, it will be plain that the motion is apparent and due to the earth's axial rotation, On the next evening she will again be seen in the west, and it will be evident that she must have risen on the same morning a little later than the sun, and during the day revolved (invisible) across the sky, keeping near to the sun on his eastern side, and becoming visible when he has set.

143. Real Motion.—After a few weeks the observer would see that, at the same hour of the evening at which Venus was first observed, she was higher above the horizon and farther east. It would be clear that this was due to a motion of the planet, real or apparent. As the earth herself moves, not west, but east, she could not make the planet appear to move east. Thus it would be plain that the motion of Venus from the horizon was her real or proper motion. From this it would also follow that she must have come into the evening sky by rising above the western horizon, and must have caught up with and passed the sun. It would be plain that her real motion was faster than the sun's eastern motion, and that she must therefore move faster than the earth. When she thus passes the sun, she is at conjunction.

After a long time, Venus would be far enough east at sunset to be visible when the stars were seen, and she would be found moving east among the stars. Just as soon as he could, the student should fix her place accu-

* This use of the words superior and inferior will be understood in studying the planets' motions.

rately in relation to the fixed stars, so that he could detect her motion among them. She moves so rapidly that her changed position would be evident the very next evening. This rapid motion makes it very interesting work to trace the path of Venus among the stars.

144. **Venus and the Ecliptic.**—One point which should be noticed in watching her is the position of her path in relation to the ecliptic. She keeps very near it, and the student should note whether she is north or south of it. But he must constantly remember what was said in 139. The unvarying nearness of the planets to the ecliptic shows that they move in planes very near it. But it does not show the exact planes of their orbits.

145. **Elongations, etc.**—The observer, watching Venus, would see her continue to get higher above the horizon, and farther east among the stars. The earth's motion in her orbit would cause many constellations in which Venus had been seen to go out of sight behind the western horizon. Finally, 219 days after superior conjunction, the almanac would contain the notice "♀ gr. El. E.," or the greatest Eastern Elongation of Venus. That is, Venus would have reached her greatest height above the western horizon, and would afterward begin to approach it. Venus would be nearly half-way between the zenith and the horizon at the earliest hour at which she could be seen on the evening of her greatest elongation. Lines drawn from the observer's eye to Venus and the sun would make an angle of about 47°. The angle varies a very little at different elongations, but the almanacs usually give the exact number of degrees. It would be a good many days before the ordinary observer without instruments would perceive that Venus was getting nearer the horizon. After a time it would be very plain. But Venus would continue to move east among the stars until about 270 days after superior conjunction, when she would begin to move west among the stars, and would continue to do so while she remained in the evening sky. Finally, 292 days after Venus became evening star, the almanac would announce, "☌ ♀ ☉ inferior," and Venus would pass the sun again as she went down. But the observer would know the exact time by the almanac only, for he would see the last of Venus some days earlier. The observer should note the point of the horizon above which Venus was last seen. It would perhaps be a little north or south of the point above which she was first seen. Thinking of her motion in relation to the horizon only, and forgetting the movement among the stars, it would seem to the observer that the figure of her motion was a long half oval with its base resting on the horizon.

146. **Increased Brilliancy.**—It would be very evident to a person who watched Venus closely, that she increased in brilliancy from the time she became evening star. She would be a splendid object when she left the evening sky. These facts would indicate that she was getting nearer to the earth all the time that she was evening star.

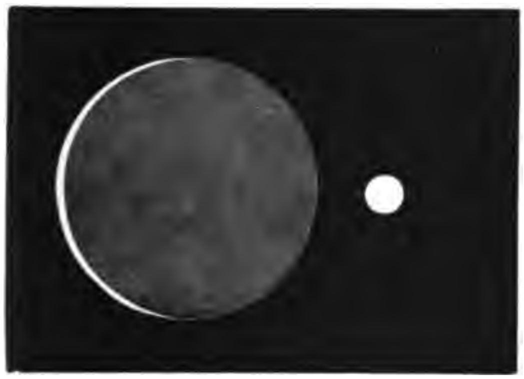
147. **Explanation, or Theory.**—If the student will cut a circle of about six inches in diameter from rather stiff paper, he will see that he can hold it west of him in such a position that it will look like a long oval, or even like a line. When held in this position, a body supposed to move around its circumference would be much nearer to the observer when on one side of it than when on the other. If the body moved in the direction in which the earth revolves round the sun, it would be at the greatest distance from the observer when it was going up, and nearest him when moving down. Now the earth's orbit, which is always in the direction of the sun, is always west of us at sunset, and only half of it is above the horizon. If Venus revolves around the sun in an orbit interior to the earth's orbit, it might be situated in such a plane as to look like a long oval, of which half was above the horizon—or even like a line. If Venus moves around it in the same direction in which the earth revolves round the sun, she would seem to move in such a long semi-oval, first up, then down; and when she passed the horizon moving up, she would be much farther from the earth and observer than when coming down. Thus this theory would account for her rising 47° and then coming down. And, as she would be getting nearer to the earth from the time that she rose above the horizon, her increased brilliancy would be accounted for. The fact that Venus is never seen opposite the sun would also be explained. It is because we never come between her and the sun.

148. **Superior and Inferior Conjunction.**—If Venus moves in an orbit interior to the earth's orbit, and in the same direction in which the earth moves round the sun, she must be farther west than the sun is when she passes him coming up into the evening sky. And, also, when she passes him moving down out of the evening sky, she must be nearer to the earth than the sun is. As Venus is always very near the ecliptic, she must be very nearly in line with sun and earth in both cases. At superior conjunction, an inferior planet, the sun and earth are nearly in line, with the sun in the middle. At inferior conjunction, they are nearly in line, with the planet in the middle.

149. **Phases of Venus.**—A telescope reveals some facts which strongly confirm this explanation of the motions of Venus. If, at superior conjunction, the earth and Venus are on opposite sides of the sun, she has the same face turned to the earth and sun. This is exactly

the position of the moon when she is full. Also, just after inferior conjunction, if she is then nearer to us than the sun is, she is in exactly the position of the new moon. Also, at her elongation, we see half of the side turned to the sun, just as we see the moon at her quadrature. Now, when Venus is observed through the telescope, she exhibits phases just as the moon does, except that she enters the evening sky a full circle and leaves it a crescent. But these changes proceed concurrently with the increase in apparent size. The full circle is much smaller than that of which the crescent forms part. Fig.

FIG. 35.



35 shows the relative proportions of Venus at her superior and inferior conjunctions.

About a month before the inferior conjunction, there is an entry in the almanac, "♀ at greatest brilliancy." The brilliancy of Venus depends on two things, her apparent size and the amount of illuminated surface. At the date indicated, the combined effect of the two is greatest. The phases of Venus show that, like the moon, she shines by reflecting the light of the sun.*

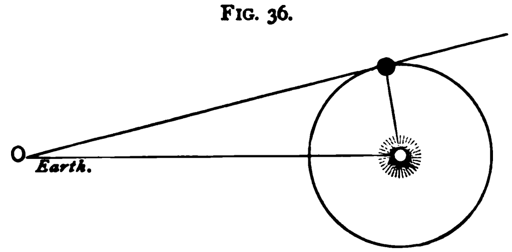
150. Transit of Venus.—The argument to show that Venus moves round the sun in an orbit interior to the earth's orbit is very strong without the aid of the facts learned from the telescope. It is irresistible with them; but it is still further strengthened. If Venus is crossing the ecliptic at her inferior conjunction, she is seen to pass across the face of the sun like a small black ball. This is called a Transit of Venus, and it never takes place at superior conjunction. Two transits only occur in a century, with an interval of eight years between them. The last two transits occurred in 1874 and 1882.

151. Venus as Morning Star.—After her inferior conjunction, we must look for Venus before sunrise in the morning sky. Her motions are the same as when she is evening star, except that they occur in inverted order. The almanac records them in order.

152. Western or Retrograde Motion.—The western or retrograde motion of Venus has not the importance or interest of the retrograde motion of the superior planets. It is not an apparent, or parallactic motion caused by our motion. If the student will take some small object, and revolve it in a circle between himself and the wall, he will see that in the parts of the circle nearest him and farthest from him, it moves in opposite directions against the background of the wall. Thus, Venus really moves up and down. We see both motions against the same background. One is in the order of the signs—Aries, Taurus, Gemini, etc.—and we are accustomed to call this eastward and direct, so we call the other western and retrograde.

153. Synodical Period.—Venus does not, like the superior planets, make an apparent revolution round the earth. But the period at the beginning and end of which she occupies the same position in regard to the sun and earth is called her synodical period. She does this at successive superior or inferior conjunctions, but she is too near the sun for us to see her. At her elongations, lines drawn between the sun, the earth, and Venus form a right triangle. The reader will see that this must be so, by examining Fig. 36. When the planet in the figure is seen at its greatest altitude, the line to the earth is a tangent to its orbit, and makes a right angle with the line from the planet to the sun. But Venus is at her greatest height above the horizon at her elongations. So we can count her synodic period in days, by the time from her eastern or western elongation back to the same. The average time is 584 days. This is also the number of days between her superior conjunctions. She is evening star and morning star 292 days each (on an average).

FIG. 36.



154. Sidereal Revolution.—We learn the period of the synodical revolution, as given above. Circular motion is measured from the center; but we are not only not at the center of the orbit of Venus, we are wholly out of it. But at her conjunctions, we can tell where she would be seen by an observer at the sun. At superior conjunction, when she is on the western side of the sun at sunset, an observer at the sun would see her where we do, on the western horizon. But at inferior conjunction, when she is between us and the sun at sunset,

* Mars shows a little indication of phases. We do not, in certain positions, see him a perfect circle.

an observer at the sun would see Venus just 180° from where we do, viz., on the eastern horizon. Therefore, but for the motion of the constellations, we would say Venus had traveled 180° while evening star. But it is evident that Venus passes through every constellation that passes the sun while she is evening star. That is, Venus, while evening star, travels as far as the sun and 180° besides. The sun's mean daily journey is $\frac{360°}{365\frac{1}{4}}$, or .986°, and his mean journey in 292 days is 288°. Therefore the mean distance traveled by Venus in 292 days is 180°+ 288°, or 468°. Her mean distance in one day is 1.6°, and she would travel 360° in 225 days. This is the period of the sidereal revolution of Venus.

155. **Mercury.**—The synodical period of Mercury occupies 116 days, though his sidereal revolution takes only about 88 days; therefore, he is evening star every alternate 58 days. This event is recorded in the almanac by the symbols "☌ ☿ ⊙ sup." But though he comes so often, there are a good many difficulties in getting a sight of him. He is never more than 28° from the sun at his greatest elongation. His orbit differs from a circle more than that of any other planet; * and, when he is at perihelion and elongation at the same time, he is much nearer the sun. Besides, he gets farther from the ecliptic than any other planet.* The most favorable times for seeing him are when he is evening star in the spring, and morning star in the fall. He is very bright when he is in the field of vision, and can not be mistaken. He, is of course, to be looked for near the horizon and ecliptic. By watching the almanac in spring and fall, for his two conjunctions, the industrious student will be sure to see Mercury in the end.

The motions of Mercury are in all respects similar to those of Venus. He moves more rapidly. He does not vary in apparent diameter nearly so much as Venus, because the diameter of his orbit, which measures the variation of his distance from us, is much less than that of Venus. (See Fig. 37.)

FIG. 37.

Phases of Mercury, and its Comparative Size as seen at Different Times.

* Except the asteroids, to be hereafter mentioned.

CHAPTER VII.

THE ATTRACTION OF GRAVITATION.

156. After learning something of the motions of the planets, it is natural that we should desire to know the force which causes them to move in their orbits.

The mere fact that the planets move, does not need to be accounted for. If we roll a ball on a slightly rough surface, it continues to move after the hand is removed, but finally stops. In proportion as we lessen friction and the resistance of the air, its motion lasts longer. Therefore, it is believed that a body moving where there is no friction and no resistance of the air would keep on moving forever. The planets are placed where there is no friction and no resistance from the air, for they carry their atmospheres with them. The continued motion of the planets is regarded as a final proof of the law of inertia, viz., a body at rest will continue at rest until some force sets it in motion, and a body in motion will continue to move until some force stops it.

But on earth bodies in motion always move in straight lines unless some force deflects their motion. If they move in a curve, they change direction continually; and therefore the force must be constant, not instantaneous, in operation.

It has always been known that some force draws bodies toward the center of the earth, and that they move in straight lines unless some other force acts on a falling body, when it moves in a curve. Thus we may throw a stone horizontally, but, since the attraction of the earth affects it, it falls in a curve. If we revolve a key fastened to the end of a string, we project it in a straight line, as is shown as soon as we let go the string. The force of cohesion in the string, holding it to the center, makes it move in a curve.

We have proof that the earth's attraction may be modified, for, when we revolve a bucket of water rapidly, the water does not fall out. So we may surmise that the moon is kept from falling to the earth by her rapid motion, and that the earth's attraction makes the motion a curve.

157. Now the great mathematician, Sir Isaac Newton, proved that the attraction of matter is the force which makes the heavenly bodies move as they do; but his arguments were nothing like these, though he took for granted the known laws of motion in his reasoning.

158. Before the time of Newton, astronomers observed the heavenly bodies as we have described in the previous chapters, except that they had instruments for measuring angles, and they subjected everything to exact measurement. They measured the apparent diameters of sun and moon, the angles which inferior planets make

with the sun at their elongations, they measured the angles through which the superior planets retrograde, and a great many other things. Since Jupiter and Saturn revolve very slowly, and since it takes much repetition of observation to insure accuracy of result, the reader can see how much slow, patient, unobtrusive work somebody did before anything definite could be known. An astronomer called Tycho Brahe collected a vast mass of accurate information. He was fortunate enough to have some property, and to find a munificent King of Denmark, who built an observatory called Uranienburg, on an island for him, and gave him a comfortable salary, so that he could watch and measure the heavens in peace and quiet. He kept at it for more than twenty years.

159. Then an astronomer called John Kepler took Tycho's measurements, and, after a great deal of hard trying and thinking, came to certain very definite results about the times, distances, and orbits of the planets. They are called Kepler's Three Laws, and they are given below:

1. All the planets move from east to west in ellipses which have the sun for a common focus.

2. The radius vector of a planet describes equal areas in equal times. (The radius vector is the moving line from the planet to the sun.) This is illustrated in Fig. 38. In order that this may be true, the planets must move fastest when near the sun.

FIG. 38.

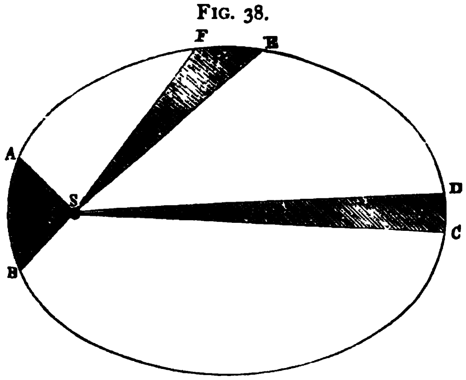


Illustration of Kepler's Second Law.

3. The squares of the periodic times (sidereal revolutions) of the planets are to each other as the cubes of their mean distances from the sun.

Now, philosophers did not consider it proved that the attraction of matter causes the planets to move in curved lines until the result of the motion had been accurately measured, and the force estimated in numbers, and shown to be mathematically equal to producing the result. To reason otherwise would be as absurd as to pronounce a piece of carpeting exactly sufficient to cover a floor, without measuring the floor and the carpeting. When, by the help of Tycho Brahe and Kepler, the times, the distances from the sun, the orbits, were accurately measured, then, and not before, it was time for somebody equal to the task to try to make a mathematical estimate of the force.

160. Sir Isaac Newton then took up the problem, and by a long chain of difficult calculation belonging to the higher mathematics showed that all the facts would be accounted for by the following law:

"Every particle of matter in the universe attracts every other particle with a force proportioned directly to the mass (or quantity of matter) and inversely to the square of the distance between them."

When we consider that, besides the sun, there are eight large planets with their moons, of various masses, and at various distances from the sun, we see what a complicated piece of calculation it is to show that this law accounts for the deflection of their motions from straight lines. Sir Isaac Newton did not finish this problem in its details, but he proved enough to make mathematicians quite confident that his solution was correct. There were certain irregularities in the motions which were not fully accounted for. These are called perturbations. Succeeding astronomers have largely supplied the details—notably two Frenchmen, Laplace and Lagrange—and fresh facts, learned by observation, have aided in this work; but there is still something to be done.

161. In 1846 there was a curious example of the way in which mathematicians have learned to reason. Some irregularities were detected in the motion of the planet Uranus. There was a very strong suspicion that some unknown planet caused these perturbations of Uranus, and two mathematicians, Mr. Adams, an Englishman, and M. Leverrier, a Frenchman, set themselves separately to calculation in order to find out the direction from which the disturbing influence must come. It was a remarkable evidence of their skill that both gentlemen directed attention to the part of the heavens in which the planet was found, and put astronomers to examining it with telescopes. The result was a double discovery, in which Leverrier had a little the advantage of time, and he is therefore called the discoverer of the planet, which was named Neptune.

162. Let us go over the steps of this statement. The merit of Copernicus was that he observed nature, just as is recommended in this book, and reasoned about these observations of himself and others. The merit of Tycho Brahe was that he went systematically to the work of taking mathematical measurements. This was a great step. Then Kepler applied these measurements to making a mathematical statement of the orbits, the times, the distances, the thing Newton was to account for. Then Newton estimated the force. This is regarded as one of the greatest achievements of the human intellect.

163. **The Tides.**—Twice a day the waters of the ocean move a short distance over the boundaries separating

sea from land, and twice a day they move back. This motion is called the tides. When the water is rising, it is called "flood-tide," and when it is falling it is called "ebb-tide." The highest point reached is called "high water"; the lowest, "low water." High or low water occurs about fifty-two minutes later every day.

It has long been known that the tides depend on the moon's motions; that they come later every day because the moon rises later. There is a vast swell, or tide-wave, on the half of the earth turned toward the moon. That we should account for this by the attraction of the moon is natural. But the waters not only rise on the part of the earth under the moon: they are at the same time high on the part of the earth turned from the moon, while they are low only between these opposite parts of the earth. Prof. Guyot thus accounts for the high tide on the side of the earth turned away from the moon: "The waters most distant from the attracting body being least affected, their weight is somewhat lessened, and they are less attracted toward the earth than those at the sides. To restore the equilibrium, the waters on the sides, which exert a greater pressure, tend to move toward the region of least attraction, and their accumulation there raises the surface of the sea slightly above its normal level, producing the second or counter wave."

The attraction of the sun also affects the tides, but, since he is much farther from us than the moon, the effect produced is much smaller notwithstanding his greater mass. But sometimes the attractions of the sun and moon act in the same direction, sometimes in different directions. Twice a month the sun and moon are on the same or opposite sides of the earth, and then the tides are much higher. These are called spring-tides. Twice a month, when the moon is in quadrature, the attractions of sun and moon act at right angles to each other, and then the tides are lower than usual. These are called the neap-tides.

The highest tides occur when sun and moon, or both, are most nearly vertical, and when they are nearest the earth. Thus they vary with every position of the two bodies.

The tide does not accompany the moon and sun, but follows a little after them. This is the result of the inertia of matter, which can not at once be set in motion. The cause is the same that makes it more difficult for horses to start a wagon than to pull it after it is once set in motion.

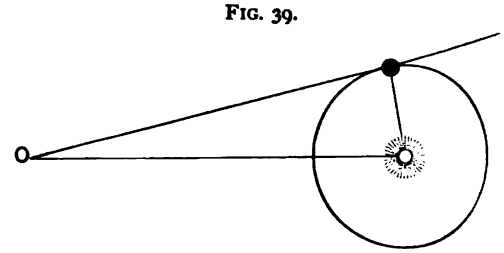
The tides vary in different places from terrestrial causes. These belong to physical geography rather than astronomy.

164. Refraction.—Refraction is the bending of a ray of light in passing obliquely from one medium to another of different density. The subject belongs to physics, but it is necessary to mention the effect the refraction of the atmosphere has on the apparent positions of the heavenly bodies. The effect is much greater nearer the horizon, since it depends on the obliquity of the rays of light, which decreases as we approach the zenith. Its effect is to make bodies on the horizon appear higher than they are. In consequence of refraction we see the sun and stars after they are below the horizon. In the latitude of Nashville, Tenn., observers are indebted to refraction for a good view of the fine first-magnitude star Canopus, which is at that place very near the boundary of the circle of Perpetual Disparition.

Astronomers, when making accurate observations, have great trouble with refraction. One trouble is that the effect varies with the density of the atmosphere, and thus it is sometimes difficult to allow for it.

165. Celestial Measurements.—Lines joining the sun and earth with each other and with a planet or the moon must form one line or a triangle. If we can get the number of degrees contained in two angles of such a triangle, we can draw a triangle similar to it, as any student of elementary geometry knows. Also, the sides of the triangle on paper will have precisely the proportions of the triangle in the heavens. One of these sides is always the distance between the earth and sun; another is the distance between the planet and sun. Thus, by measuring the lines on paper, and getting the ratio, we compare the distances of the earth and the planets from the sun. In this way the proportions of the solar system were long ago learned.

Fig. 39.

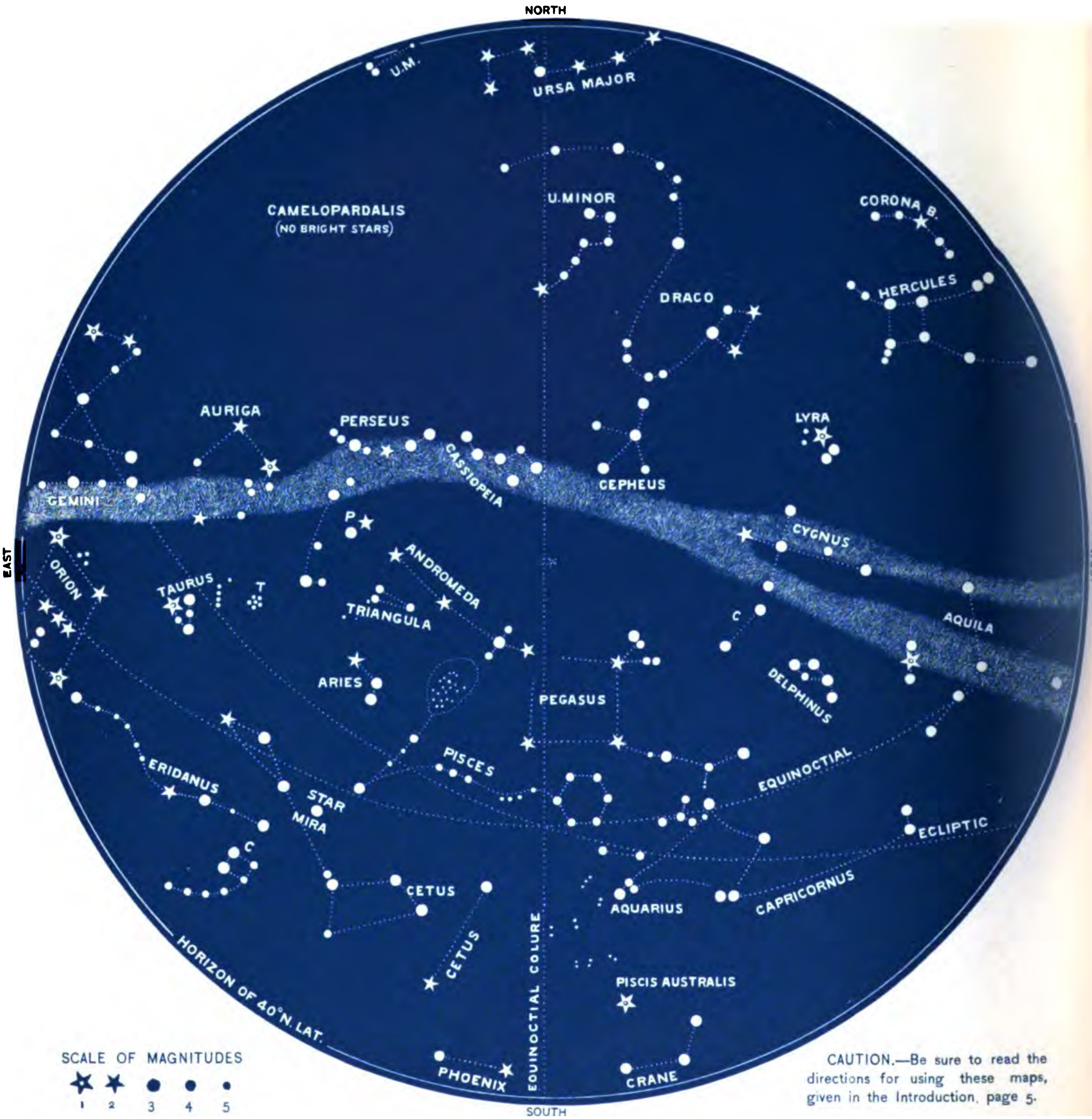


The simplest example of such a triangle is given by Venus and Mercury at their greatest elongations. The triangle, as seen in Fig. 39, is a right triangle. One of the other angles is very easily found by measurement. If lines be supposed drawn from the observer's eye to Venus and to the sun, they form an angle of the triangle represented in Fig. 39. At the time of her greatest elongation, Venus can be seen at sunset with a good telescope, and thus this angle can be measured without difficulty. Nothing will give so much reality in the student's mind to such triangles as to note the positions carefully in nature at the elongation of Venus, and, getting the angle of elongation from a good almanac (which always gives it), to draw a similar triangle on paper. If correctly drawn, the lines representing the distances of Venus and the earth from the sun have the proportion of two to three nearly.

If we can get one of the sides of such a triangle in miles, it is evident we can get the others, since we can get the proportions existing between the lines. This is done by making the

MAP III.

For Study of the Stars from October 22d to January 20th.



CAUTION.—Be sure to read the directions for using these maps, given in the Introduction, page 5.

THE HEAVENS

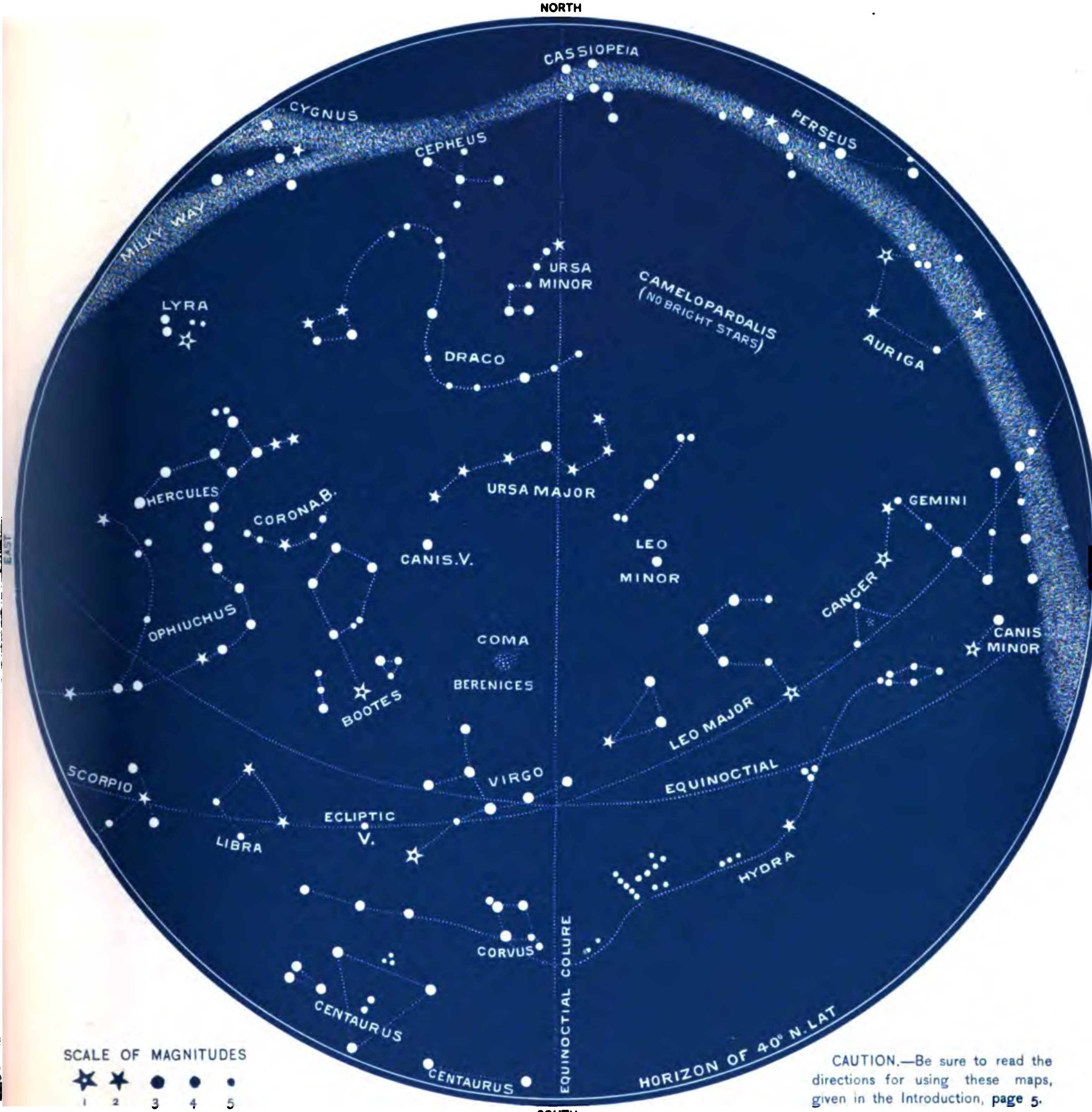
AS SEEN

September 22d at midnight, November 7th at nine o'clock,
October 23d at nine o'clock, November 22d at eight o'clock.

MAP IV.

For Study of the Stars from April 26th to July 22d.

NORTH



CAUTION.—Be sure to read the directions for using these maps, given in the Introduction, page 5.

SOUTH

THE HEAVENS

AS SEEN

March 21st at midnight,
April 20th at ten o'clock,
May 5th at nine o'clock,
May 21st at eight o'clock.

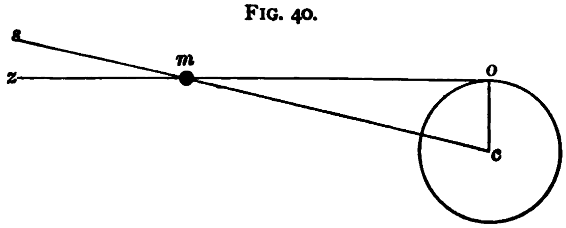
earth's radius the side of a triangle. In order to understand this, it is necessary to discuss parallax a little.

166. Parallax.—Let us suppose that we note the direction of some body from us by drawing a line to the center of its position from the center of ours. If we move off the line, the body is displaced on the background against which we see it. If we draw another line between the centers of the bases, it forms an angle with the former line. This change in the direction of a body, as seen from two different positions, is called its parallax. The retrograde motion of the planets is a parallactic motion. The angle measures the parallax, or difference in direction.

From the previous discussion of these apparent motions, the student knows that bodies undergo parallax in proportion to their nearness to us. The moon is the heavenly body nearest us. If two observers, at widely separated points of the earth, observe the moon at the same time, carefully noting her position on the starry sphere, so as to compare observations, they will find they do not see her against the same point of the sphere. Thus, the moon undergoes parallax, and, by measuring the angular distance between the two points of the sphere, we measure the moon's parallax.

When the moon is on the horizon, a line from her to the observer is a tangent to the earth. The earth's radius forms a right angle with it. In Fig. 40 the right triangle *m o c* has for

FIG. 40.



one side the earth's radius, *o c*, a line of known length. The observer at *o* sees the moon in the direction *o m z*. From the center of the earth the moon is in the direction *c m s*. The difference in the direction of these lines is called the moon's horizontal parallax. It is the difference made in the direction of a body by seeing it from the surface, instead of the center, of the earth. The angle *s m z*, or its vertical angle *c m o*, measures it. This angle bears such a relation to the moon's parallax, ascertained, as has just been related, by observation, that when we know the one we can compute the other. Then, in the triangle *c m o*, we have two angles, and a side, *c o*, in miles. We easily find another side, *c m*, which is the moon's distance from the earth's center, in miles.

167. The Sun's Distance from the Earth in Miles.—In all the triangles formed by the sun, the moon, and a planet, the earth's distance from the sun is one side. If we know this in miles, we can, from the proportional triangles, find all the other distances in miles.

Next to the moon, Mars and Venus are the heavenly bodies nearest us. Both undergo parallax when observed at widely separated stations on earth. When they are nearest to us, the parallax is greatest. Venus is nearest at her inferior conjunction, but we do not see her when the stars are visible, so we have ordinarily no fixed object by which to measure the parallax. But twice in a century Venus makes a transit over the face of the sun, and astronomers then use the sun's face as a background on which to estimate the parallax of Venus. The points to be observed are, the first and last contact with the sun, and the distance from the center. When this parallax is known, the horizontal parallax of Venus can be estimated, and her distance from the earth learned, as the moon's distance was found.

It is impossible to estimate the sun's parallax directly, but since the distance of Venus from the earth, and the sun's distance from the earth, form sides of the same triangle, we can find the sun's distance by knowing that of Venus.

The last transits took place in 1874 and 1882. The correct estimate of the sun's distance from the earth is so important that on both occasions the governments and scientific men of the civilized world interested themselves in fitting out expeditions to every quarter of the globe to make observations. There were years of preparation, in which new and accurate instruments were made, and even invented, and modes of investigation studied.

When Mars is nearest to us, he shows sensible parallax. He is always nearest at opposition. Every fifteen years the increase in the luster of Mars at opposition is much greater than usual. Fig. 32, page 42, shows that the oppositions of a superior planet take place at different points of its orbit. This variation in brightness, therefore, leads us to suspect that its orbit is not a perfect circle. The orbit of Mars is very eccentric, and this is the cause of the remarkable variation in brilliancy.

At long intervals Mars is at opposition when he is at the point of his orbit nearest the sun; and the earth is at the point of hers most distant from the sun. Mars then rivals Jupiter in size. This occurred in 1877. As the apparent increase in the size of Mars was due to his near approach, it afforded a good opportunity for estimating his parallax, and from it that of the sun. This was done with great care in 1877.

NOTE.—In the next and the succeeding chapters much use will be made of information learned by the telescope. In the Appendix B there will be found an account of the telescope, which is taken principally from Lockyer's "Astronomy."

PART II.

GENERAL ACCOUNT OF THE SOLAR SYSTEM.

168. The Solar System consists of the sun and the heavenly bodies revolving round him as a center.

The revolving bodies are the planets, with their moons or satellites, revolving meteors, and comets. The earth, on which we live, is one of the planets, and therefore the Solar System is much more interesting to us than any other part of the heavens.

Chapter VIII will treat of the Sun; Chapter IX, of the Planets; Chapter X, of Meteoroids and Comets.

CHAPTER VIII.

THE SUN.

169. The sun* subtends an angle of 32′, or a little more than half a degree. That is, it would take about three hundred and thirty suns, placed touching each other, to extend across the sky. The sun's diameter is 866,400 miles. This is nearly four times the diameter of the moon's orbit, which is 240,000 miles. If, therefore, the center of the sun were placed at the center of the earth, the sun's circumference would be nearly twice as far from us as the moon's orbit now is, and the sun's body would fill the whole intervening space (see Fig. 41). The sun's volume is 1,305,000 times as great as the earth's volume. But the sun is only about one fourth as dense as the earth. Fig. 42 shows the size of the sun as compared with the chief planets. The black circle represents the sun's disk. The mass of the sun is about 750 times that of all the planets and moons put together.

FIG. 41.

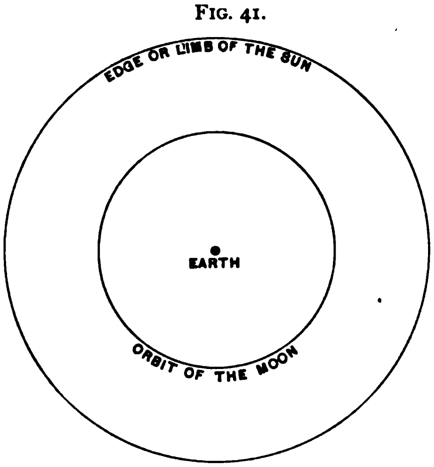
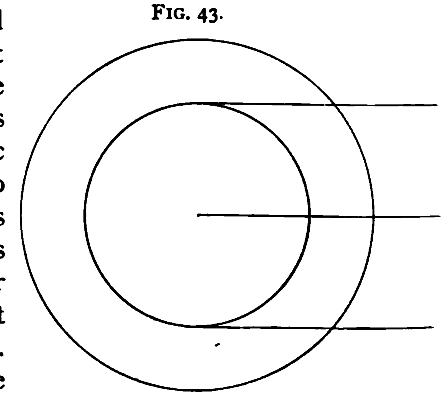


FIG. 42.

Relative Size of the Sun and Planets.

170. **Light.**—The surface of the sun is a hundred and ninety thousand times as bright as would be a candle-flame of the same size. It is a hundred and forty times as bright as the calcium or lime light, and compares with the voltaic arc as three and a half to one. On the sun's disk the brightness is greater at and near the center than at the circumference. This is owing to the greater thickness of the sun's atmosphere, which a ray from the margin must penetrate in order to reach us. Rays from the center cross by a shorter line, as is shown in Fig. 43.

FIG. 43.



171. **Heat.**—Only a small portion of the heat radiated by the sun reaches the earth. Prof. Young says: "If we could build up a solid column of ice from the earth

* In this book the study of the sun has been deferred until after the discussion of the motions of the solar system has been completed, in order to avoid a wide and long digression on the subject of the sun's telescopic appearance and physical condition. To ordinary students the investigation of the motions is the most important part of astronomy, because not only can all persons see these motions in nature, all must see them, and not to understand any important part of the order of nature brought before our eyes encourages habits of stupidity.

to the sun two miles and a quarter in diameter, spanning the inconceivable abyss of ninety-three million miles, and if the sun should concentrate his power upon it, it would dissolve and melt, not in an hour, not in a minute, but in a single second."

The Spectroscope.

172. In studying the physical constitution of the sun much use is made of an instrument called a spectroscope, and it is therefore necessary that the principles of its construction should be understood by the student.

173. When light from a luminous gas or vapor passes through a prism, and is thrown on a screen in a darkened room, it is found to produce a band, or spectrum, consisting of a bright-colored line or lines, separated by dark spaces. In Plate I examples of such spectra are given. Spectra like this are called Bright-lined Spectra.

The various chemical elements can be brought to the state of vapor and made to produce spectra. Each substance has its own spectrum, different from all the others, and it always presents the same appearance when magnified to the same degree. The numbers of the lines in the spectra of the different elements differ greatly, and are of different colors, and thus each element can be identified by its spectrum. If a compound is used, its spectrum will exhibit the lines of all its elements.

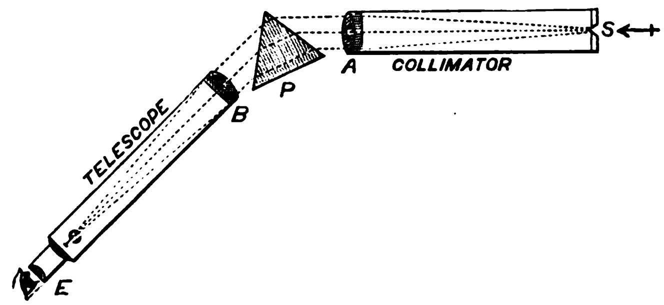
174. When the light from an incandescent solid or liquid passes through a prism, the spectrum consists of bands of color containing no transverse lines. If, however, this light passes through a luminous vapor before entering the prism, it will consist of a colored band with transverse dark lines on it; and the dark lines will correspond exactly in position with the bright lines which would be contained in the spectrum formed by passing the light of the luminous gas through a prism. The position of the lines is due to the greater or smaller refrangibility of the rays producing them, and thus it is evident that the vapor absorbs rays having the same degree of refrangibility as those which produce bright lines. This is called a Reversed Spectrum.

175. By comparing the positions of the lines in bright and dark lined spectra, and finding the lines which have the same position in both, the vapor causing the dark lines can always be identified. This is shown in Plate I, where the spectrum of light coming from the sun is compared with the spectra of light coming from various chemical elements in the state of vapor.

The knowledge of these facts has given rise to a new method of chemical analysis, of extreme delicacy and great accuracy, which has the further advantage that it can analyze substances by light which is brought from any distance, however great. Thus it can be applied to the light coming not merely from the sun, but also from the fixed stars.

It has given rise to an entirely new branch of astronomy. Spectrum analysis is thus far the great discovery in the lifetime of the present generation of middle-aged people. The essential parts of a spectroscope (Figs. 44

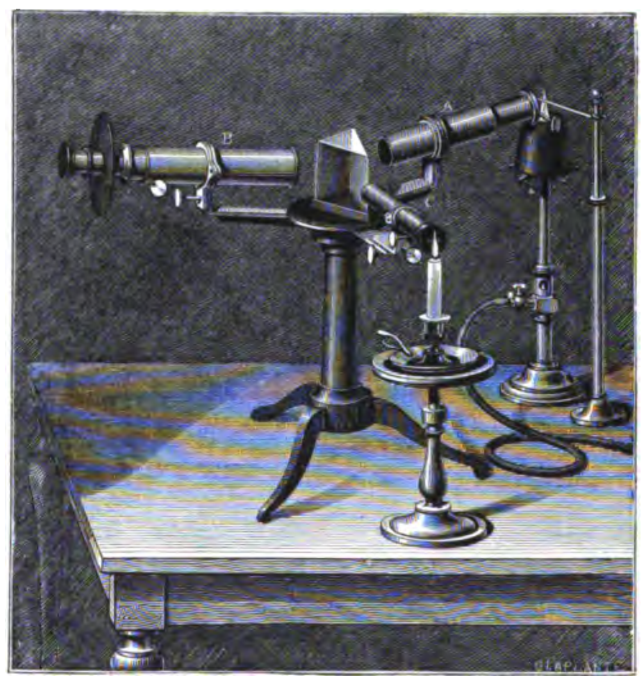
FIG. 44.



Arrangement of Prismatic Spectroscope.

and 45) are—(1) the prism; (2) the collimator-tube, through which the light under study passes to the prism; and (3) the telescope. The lens A collects the light, and

FIG. 45.



the telescope is used to magnify the image. Sometimes the light is made to pass through several prisms.

176. **Motion detected by the Spectroscope.**—The sensations of light and sound are both the results of wave-motion. The undulations of the air convey sound; those of the supposed ether convey light. A sound of high pitch is produced by the shorter waves, and a sound of

low pitch by the longer waves. The shorter waves of ether produce the more refrangible colors of light; the longer waves the less refrangible. Now a prism separates and arranges the colors on a spectrum, from red to violet, in the order of their refrangibility.

It is a well-known fact that the whistle on a moving train of cars has its pitch gradually raised if the train is approaching the hearer, and lowered if the train is receding from him. It is generally true that sounds moving swiftly from us gradually fall in pitch; those moving toward us rise in pitch. It is found, when we examine the spectrum of a rapidly moving light, that the lines are displaced. If the light is moving from us, the lines are bent toward the end of the spectrum at which the red rays appear; but, when the light moves toward us, the lines are bent toward the violet rays (the least refrangible). Thus the spectroscope enables us to tell whether a luminous gas is in motion, and also whether it moves toward us or from us. Fig. 46 illustrates this displacement of lines.

177. **Solar Spectrum.**—The spectrum formed by passing the sun's rays through a prism is a reversed or dark-lined spectrum. It is crossed by a number of dark lines, and we can match in it the bright lines of many elements that we know. Prof. Young has given a table of the elements, some lines of which have been found in the solar spectrum.

ELEMENTS.	Bright lines in spectrum.	Lines reversed in solar spectrum.	Observer.
1. Iron	600	460	Kirchhoff.
2. Titanium	206	118	Thalen.
3. Calcium	89	75	Kirchhoff.
4. Manganese	75	57	Angström.
5. Nickel	51	33	Kirchhoff.
6. Cobalt	86	19	Thalen.
7. Chromium	71	18	Kirchhoff.
8. Barium	26	11	Kirchhoff.
9. Sodium	9	9	Kirchhoff.
10. Magnesium	7	7	Kirchhoff.
11. Copper?	15	7?	Kirchhoff.
12. Hydrogen	5	5	Angström.
13. Palladium	29	5	Lockyer.
14. Vanadium	54	4	Lockyer.
15. Molybdenum	27	4	Lockyer.
16. Strontium	74	4	Lockyer.
17. Lead	41	3	Lockyer.
18. Uranium	21	3	Lockyer.
19. Aluminium	14	2	Angström.
20. Cerium	64	2	Lockyer.
21. Cadmium	20	2	Lockyer.
22. Oxygen α	42	12 ± bright	H. Draper.
Oxygen β	4	4?	Schuster.

It will be seen by this table, given above, that the lines are not fully matched. Also, the lines of a number of well-known elements are not found at all in the sun. It is thought that these results are due to the sun's high

FIG. 46.

Changes in the C Line (September 22, 1870).

temperature, since the spectra of luminous bodies are much affected by temperature.

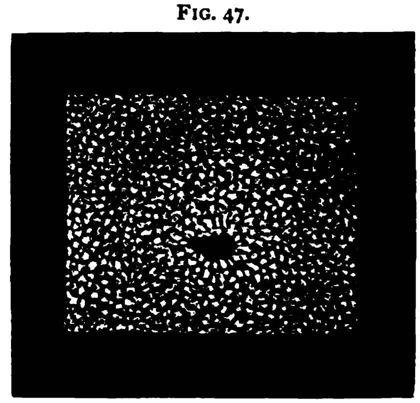
The Sun's Telescopic Appearance and Physical Constitution.

178. The most competent authorities now believe that the sun is a great sphere of gas, extremely condensed at the center by the weight of the outer parts.

The sun's *Photosphere*, or visible surface, is a stratum or coating of luminous clouds floating in the sun's atmosphere, and surrounding the gaseous portion at the center. The *Chromosphere* surrounds the photosphere, and consists of very red flames extending about six thousand miles in every direction from the photosphere. The *Corona* is a faint pearly halo resembling the tails of comets, and it radiates from the sun to an immense distance in every direction.

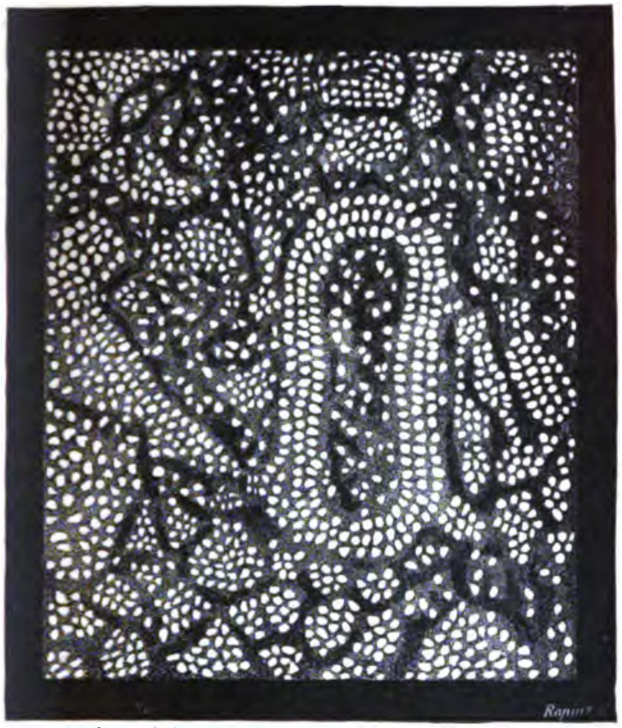
179. **The Photosphere.**—In a telescope of moderate power the photosphere seems to be composed of small incandescent grains separated by a somewhat darker medium. They form streaks and groups. With higher power of the telescope these granules seem formed of still smaller grains. They must, at different times, vary somewhat in form, having been compared by different observers to rice-grains and willow-leaves. They are really incandescent clouds floating in the sun's atmosphere, and composed of metallic vapors. Like the clouds on the earth's surface, they are partially condensed. With a low power of the telescope, the surface of the sun covered

FIG. 47.



by the grains looks like curdled milk. The light of the sun comes chiefly from these granules. They are seen in Figs. 47, 48.

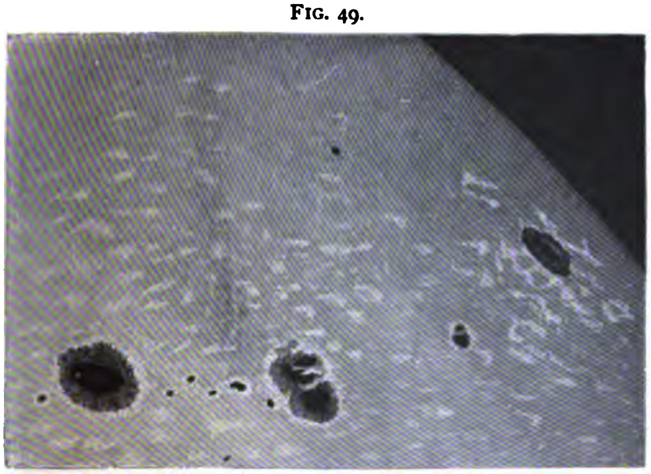
FIG. 48.



Granules and Pores of the Sun's Surface. (After Huggins.)

180. Besides the granules, there are found on the sun brighter streaks looking a little like foam, and called faculæ. They are seen in Fig. 49. The faculæ are portions of the photosphere elevated above the rest, as is

FIG. 49.

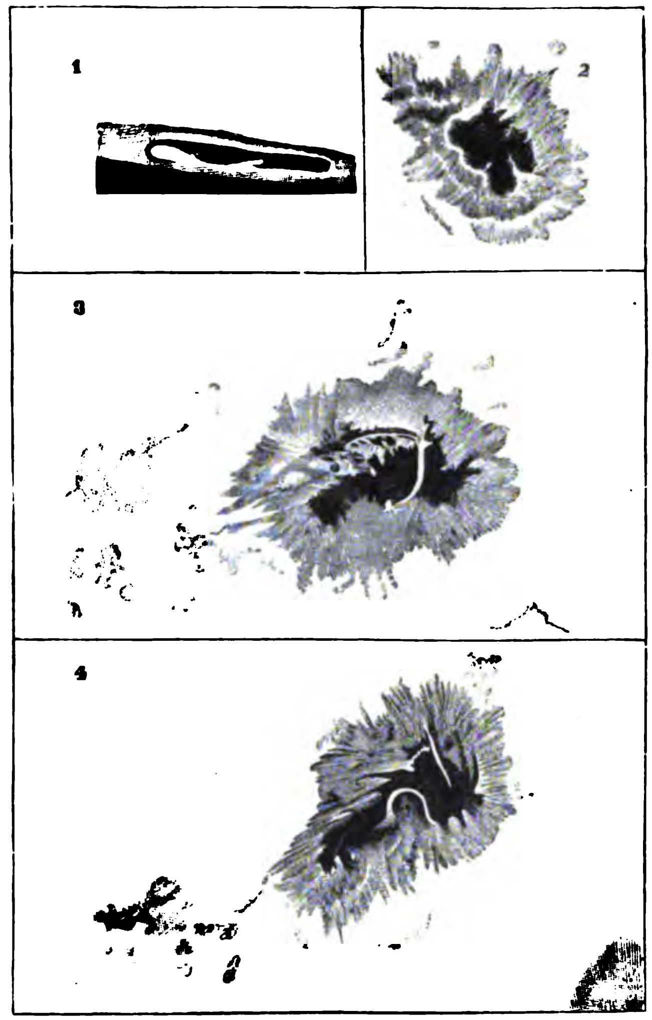


Sun-spots and Faculæ. (From a Photograph.)

seen when they are on the edge of the sun. They then project a little beyond the circumference. They are most common near the edge of the sun, which, as was said, is darker than the middle.

181. Sun-Spots.—In addition to the granules and faculæ on the surface of the sun, there are spots which have been the subject of a great deal of study. Three large and several small ones are on the portion of the sun's surface shown in Fig. 49. A sun-spot consists of two parts, the umbra and the penumbra (see Fig. 50). The umbra is in the center and appears dark, but this is merely in contrast to the brightness of the granulated

FIG. 50.

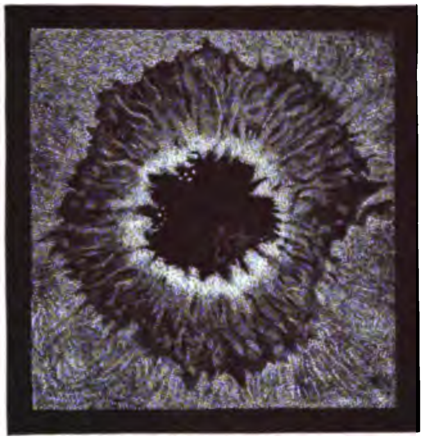


The Great Sun-spot of 1865.—1. The spot entering the Sun's disk, Oct. 7th (foreshortened view). 2. Its appearance, Oct. 10th. 3. Central view, Oct. 14th, showing the formation of a bridge, and the nucleus. 4. Its appearance, Oct. 16th.

photosphere. It is in reality filled with bright clouds. The penumbra consists of gray filaments arranged so as to radiate from the center (see Figs. 50, 51, 52, 53). An irregular but well-marked outline separates the penumbra from both umbra and photosphere. The photosphere around the penumbra is often intensely bright. Some penumbral filaments end in granules of very bright matter. These appear to sink and dissolve, while others

take their places. The penumbra seems to be drawing in luminous matter all the time. In a few of the spots, the inner ends of the penumbral filaments curve spirally, and the spots revolve as if affected by a cyclone. Large spots sometimes seem to have two different centers of cyclonic action. But the revolution does not last, and in fact such spots are not numerous.

FIG. 51.



Spot of July 16, 1866.

Sun-spots are usually circular when fully formed. Their formation is gradual; their coming being indicated by faculæ at the point, and by small black dots which grow larger, and finally a spot is developed which lasts, on an average, two or three months. Eighteen months has been about the longest duration of any sun-spot known. Sun-spots are sometimes of immense size. The largest spot was observed in 1858. It had a diameter of a hundred and forty-three thousand miles. One of thirty or forty thousand miles can easily be seen with no further aid than a bit of smoked glass. They generally come in small groups. They move across the face of the sun which we see, in about twelve or thirteen days, after which they disappear; but when another period of the same length has elapsed, sun-spots, which can unquestionably be identified as the same, are found coming again on the eastern part of the sun. This is evidently the result of the sun's rotation on its axis. It is a curious fact that the motion of the sun-spots in different latitudes indicates that the part of the sun near the equator rotates more rapidly than the portion farther removed from that circle. At the equator, the rotation seems to be performed in about twenty-five days.

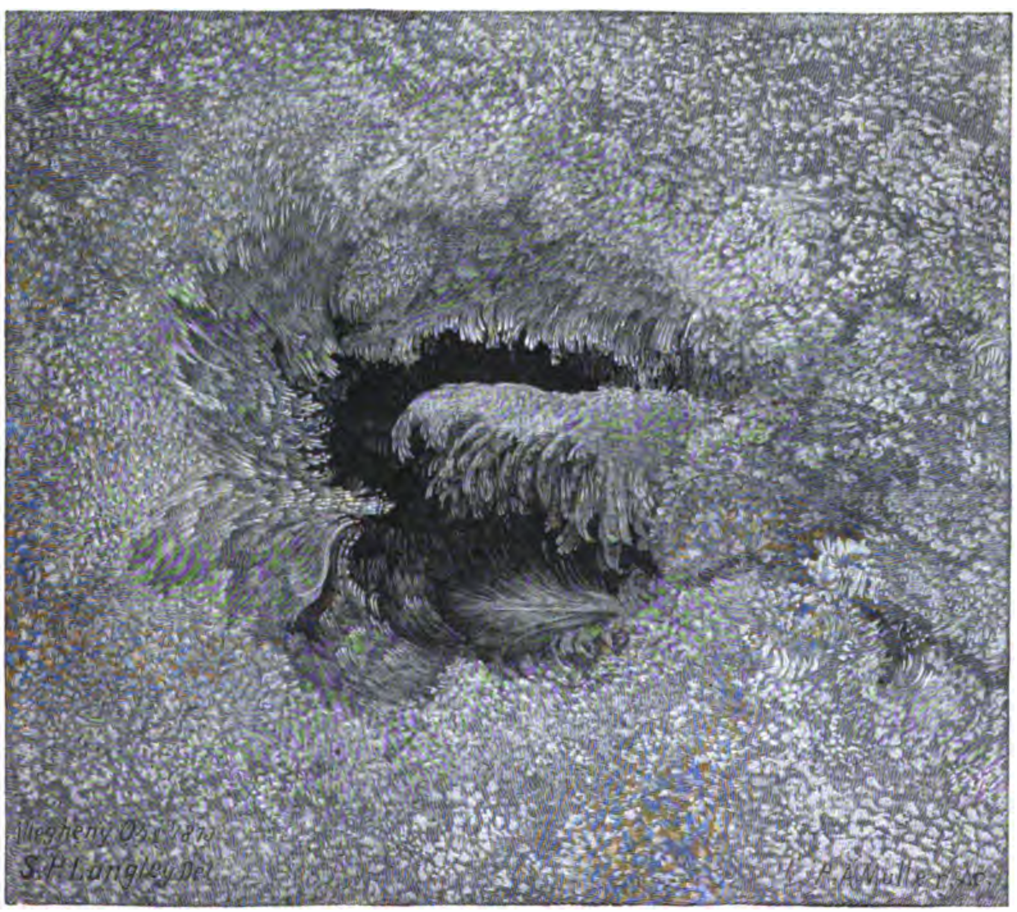
The spots are not found equally distributed on all parts of the sun. They occur chiefly in two zones on each side of the equator, as shown in Fig. 54. These zones are between the latitudes 10° and 30°. Sun-spots have been seen but once beyond latitude 45°.

The spots seem to move across the sun from east to west, but it is evident that the side of the sun's face turned toward us corresponds to the part of the earth's surface which is below the horizon of the person observing him. It is evident that the part of the sun's surface which we see, rotates on his axis in the same direction with the part of the earth's surface which is below our horizon. It is clear from this, that the sun's axial rotation is in the same direction as the earth's motion. It is merely a result of the ambiguity in our use of the words east and west, when we say the sun rotates from west to east.

It is evident that the sun-spots have a motion of their own, as well as that caused by the sun's rotation.

The curves made by the spots, as seen in Fig. 55, show that the

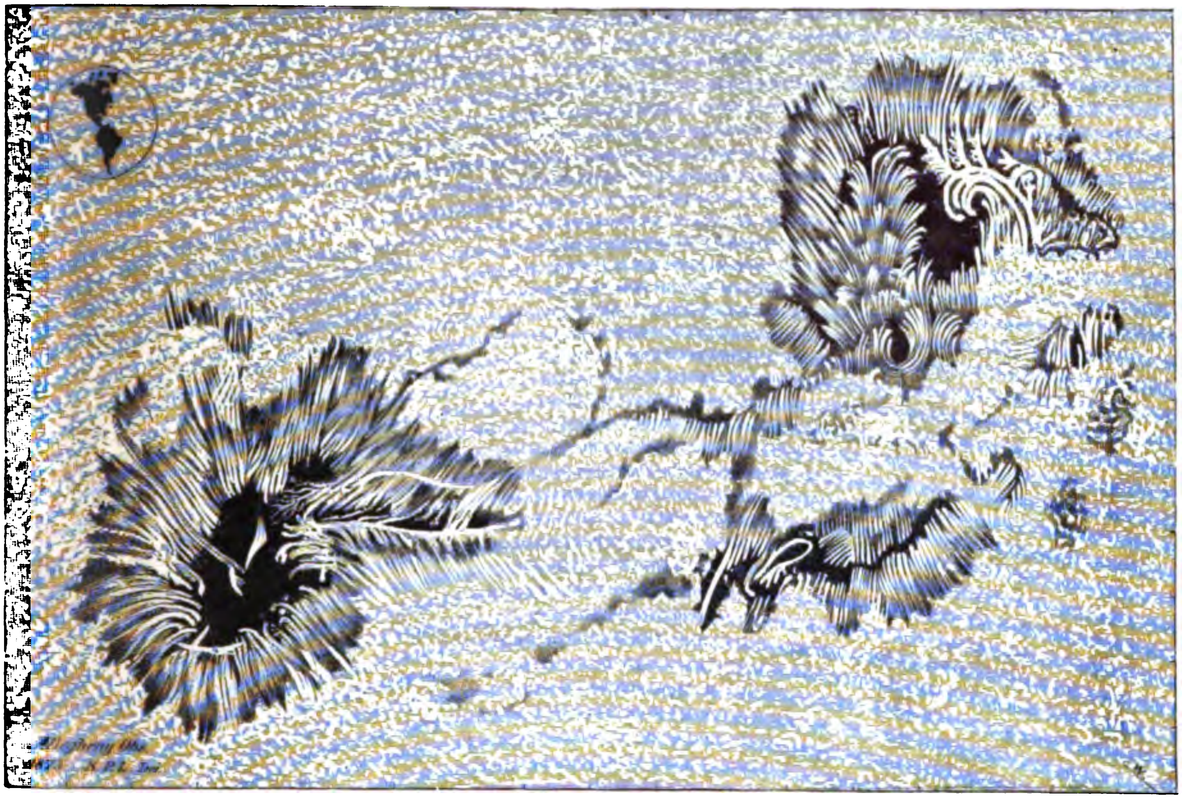
FIG. 52.



A typical Sun-spot.

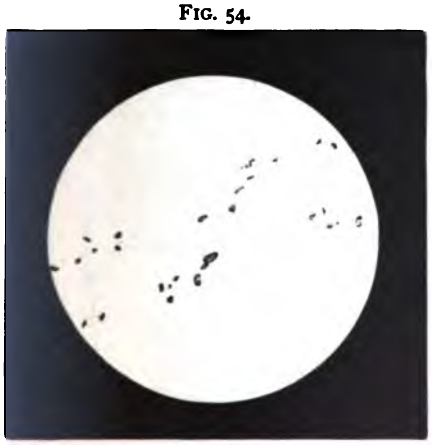
sun's axis is inclined to the plane of the ecliptic. That the sun-spots are depressions in the photosphere is shown by the changes wrought by perspective in one which travels across the sun's face. This is seen in Fig. 56. While the spot is on the western side of the sun, nothing is visible but the western side of the penumbra. As it advances east, the umbra begins to be seen; then, as it passes directly in front of us, we see the whole umbra and the penumbra all round it; then the western side of the penumbra goes out of sight; then the umbra, and finally we see only the eastern side of the penumbra.

FIG. 53.



Sun-spots as seen by Prof. Langley.

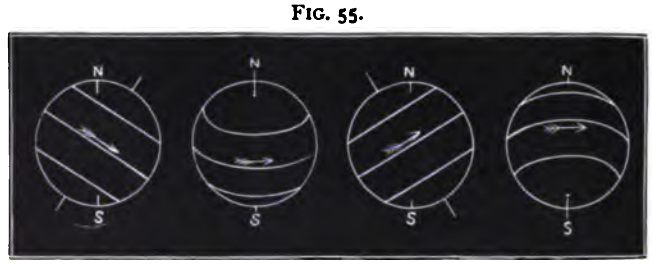
FIG. 54.



Observation shows that during periods of about eleven or twelve years there is an alternate increase and decrease in the activity which creates sun-spots. In size and number they reach a maximum and minimum. It also shows that the increase and decrease coincide with the increase and decrease of magnetic disturbances on earth, which have a period of eleven years.

182. The Chromosphere. — This word signifies color sphere. The chromosphere consists of fiery rolling flames of a vivid scarlet color. From the chromosphere, red clouds, called the "solar prominences," rise into the region of the corona. Owing to the blinding brilliancy of the photosphere, they can not be seen upon the sun's disk, and were first discovered at total solar eclipses, around the circle of sun and moon. It was supposed impossible to examine them at any other time but on these rare occasions, on account of the diffused reflected light in the earth's atmosphere. But the spectroscope, which has revealed so many secrets, came to the aid of the astronomers.

FIG. 55.



Apparent Paths of the Spots across the Sun's Disk, as seen from the Earth at different times of the year. The arrows show the direction in which the Sun rotates.

Dispersion is, as the name shows, a separation or spreading out of the rays of light. A spectroscope of high dispersive power* makes the band of the spectrum

* The dispersive power of a spectroscope is increased by passing the light through a great number of prisms.

ERUPTIVE PROMINENCES.

Scale, 75,000 miles to the inch.

Prominence as it appeared at half-past twelve o'clock, September 7, 1871.

As it appeared half an hour later, when the up-rushing hydrogen attained a height of more than 200,000 miles.

Flames.

Cyclone.

Vertical Filaments.

Spot near the Sun's limb, with accompanying jets of hydrogen, as seen October 5, 1871.

Jets.

Spikes.

Sheaf and Volutes.

As seen at 2.15 P. M.

As seen at 3.30 P. M.

As seen at 2.45 P. M.

Three figures, of the same prominence, seen July 25, 1872.
100,000 miles to the inch.

QUIESCENT PROMINENCES.

Scale, 75,000 miles to the inch.

Stemmed.

Diffuse.

Horns.

Filamentary.

Plumes.

Clouds.

longer, and the spaces between the transverse lines broader. The light between the lines is greatly weakened by it, but the brilliancy of the lines is not at all diminished. The spectrum of the solar prominences is a bright-lined spectrum, and that of the direct and reflected solar light is a reversed spectrum. Therefore, by using a spectroscope of great dispersive power, astronomers weaken the light which obscures the light of the prominences, so that they are now studied at any time with as much ease as during a solar eclipse.

FIG. 56.

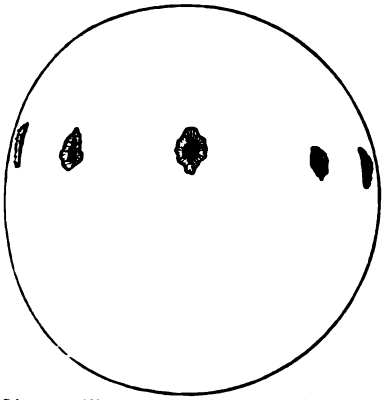
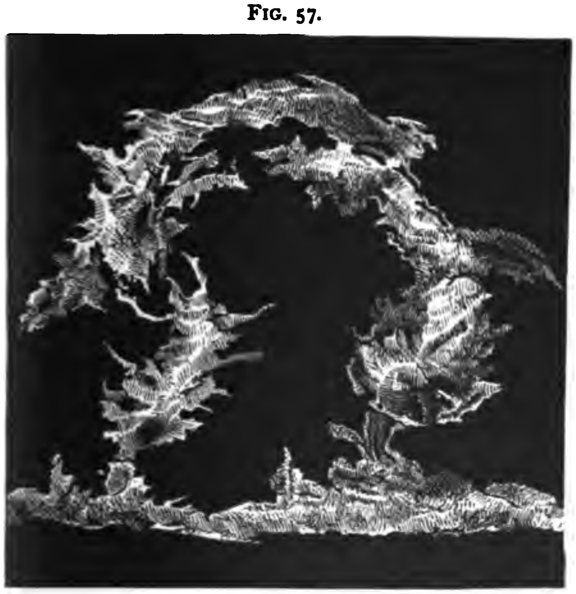


Diagram illustrating the Fact that Sun-spots are Hollows in the Photosphere.

The solar prominences are of two kinds, the Quiescent and the Eruptive Prominences.

183. The Quiescent Prominences change very gradually and look like masses of red clouds, which, when fully seen, are found joined to the chromosphere by slender trunks, as seen in Fig. 57. The spectroscope

FIG. 57.



shows that they owe their red color to hydrogen. These prominences are seen all round the sun.

184. The Eruptive Prominences are flames which burst forth near sun-spots, and are therefore not found near the poles. They change very rapidly, showing a great variety of transformations. The spectroscope proves that they are largely due to the vapors of sodium, magnesium, barium, iron, and titanium. For this reason they are called metallic prominences (see Figs. 58, 59). The chromosphere always shows the lines of hydrogen, and sometimes the lines of the elements belonging to the metallic prominences. It also contains some lines which have not been identified as belonging to any element that we know.

FIG. 58.

FIG. 59.

185. The Corona.—(See Figs. 60, 61, 62, 63.)—The corona can be seen only when there is a total eclipse of the sun, and, as this lasts but for a few minutes, the opportunities for observing it have been limited. At the

FIG. 60.

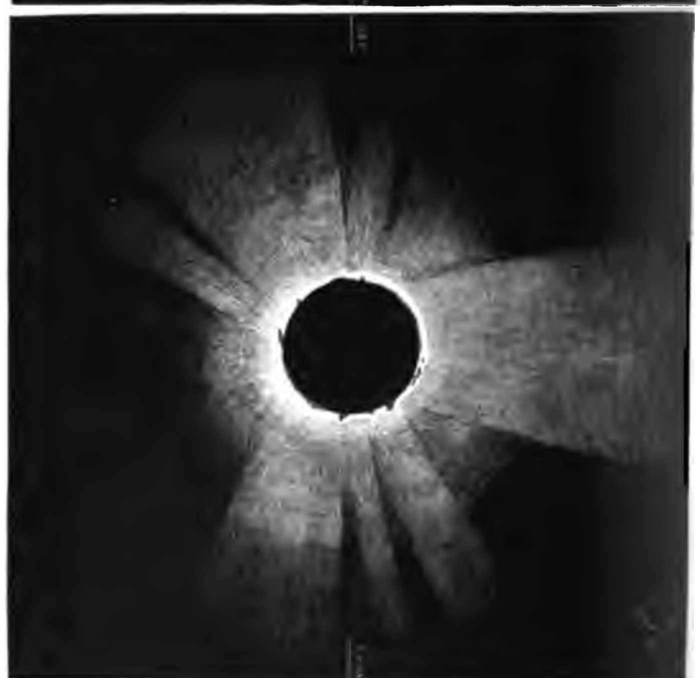
Corona as observed by Liais in 1857.

Corona of 1887. (Grosch.)

Corona of 1878. (From Combination of Various Drawings.)

Corona of 1871. (Fomander.)

Corona of 1869. (Schott.)



Corona of 1860. (Secchi.)

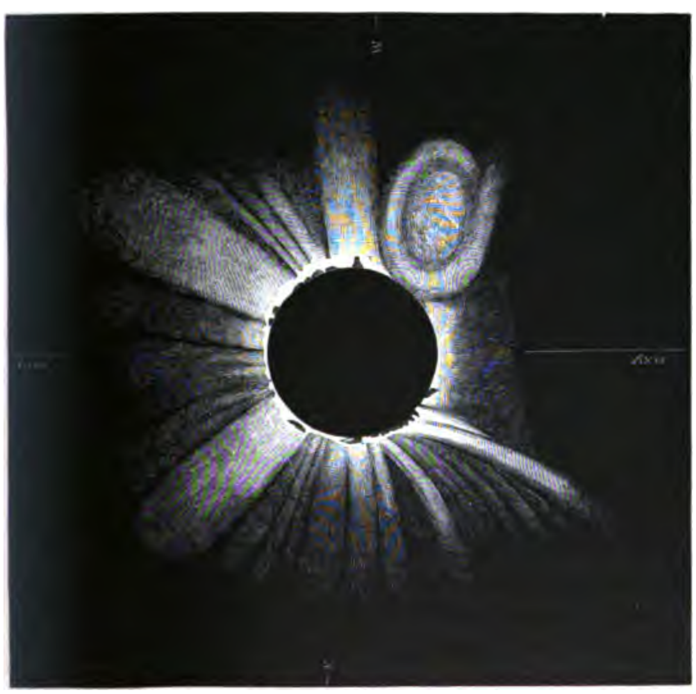
Corona of 1868. (Bullock.)

time of a total eclipse, the moon looks like a dark sphere in the middle of a halo formed of "radiant filaments, beams and sheets of pearly light. The portion nearest the sun is of dazzling brightness, but still less brilliant than the red prominences which blaze through it like carbuncles.

FIG. 61.

Corona of 1871. (Captain Tupman.)

FIG. 62.



Corona of 1860. (Tempel.)

Generally, this inner corona has a pretty uniform width, forming a ring three or four minutes of an arc in width, separated by a somewhat definite outline from the outer corona, which reaches to a much greater distance and is more irregular in form. Usually there are several rifts, as they have been called, like narrow beams of darkness extending from the edge of the sun to the outer night, and much resembling the cloud-shadows which radiate from the sun before a thunder-shower; but the edges of these rifts are frequently curved, showing them to be something else than real shadows. Sometimes there are long bright streamers, as long as the rifts, or longer. On the whole, the corona is usually less extensive and less brilliant over the solar poles, and there is a tendency to accumulations above the middle latitudes or spot-zones."

FIG. 63.

Corona of 1871. (From Photographs of Mr. Davis.)

The spectrum of the corona is remarkable for containing one bright line sometimes called "1474," more generally "the coronal line," which comes from some element with which we are entirely unacquainted; and which when in vapor (if it ever is anything else) is far lighter than hydrogen, the lightest substance we know, There is a dark line corresponding to it in a spectrum of light from the face of the sun. The corona also shows faint traces of hydrogen, and some dark lines belonging to the solar spectrum.

The corona must be composed chiefly of gas, but it probably contains some minutely divided particles which reflect sunlight.

CHAPTER IX.

THE PLANETS—GENERAL ACCOUNT.

186. The planets are arranged according to size in two classes, called respectively the Major and the Minor Planets.

187. The Major Planets are Mercury, Venus, the Earth, Mars, Jupiter, Saturn, Uranus, and Neptune. Mercury, Venus, Mars, Jupiter, and Saturn were all known to the ancients. Uranus was discovered by Sir William Herschel in 1781. It can be seen by the naked eye as a star of the sixth magnitude. It can, however, hardly be identified by any but an experienced observer who knows where to look for it, as its apparent size is so small and it moves so slowly. The discovery of Neptune has already been described.

188. The Minor Planets.—Besides the planets just named, there are a large number of small planetary bodies revolving round the sun between the orbits of Mars and Jupiter. They are called the Minor Planets, or Asteroids.

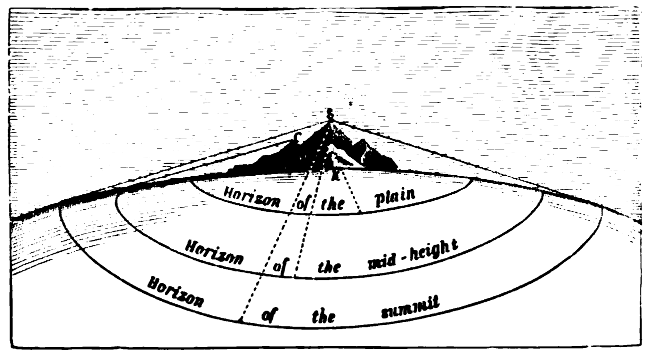
In the following list, the planets are named in the order of their distances from the sun, beginning with the one nearest the center: Mercury, Venus, the Earth, Mars, the Asteroids, Jupiter, Saturn, Uranus, Neptune. The distances from the sun increase with some regularity, and it was long noticed that there seemed to be a gap between Mars and Jupiter, so it was thought that some unknown planet might fill it. Early in the present century, four very small planets were discovered and called Juno, Ceres, Pallas, and Vesta. In 1843 another, called Astræa, became known; and since then more than two hundred have been found. New ones are often discovered. Many of them are very minute bodies.

Except Mercury and Venus, all the known planets are superior planets; that is, they revolve round the sun in orbits exterior to the earth's orbit. Their motions correspond to the motions of the superior planets described in Chapter VI. The angle through which their movement appears to retrograde, decreases as their distances from the sun increase.

In this book, the forms, volumes, densities, etc., of the planets are described together under these respective heads, because the student gains much more definite ideas by comparison.

189. Forms of the Planets.—The earth is one of the planets, and it will be best to speak of her figure first. The earth is round, or a sphere. We know this from a variety of facts: 1. The shadow of the earth, as seen on the moon when she is eclipsed, is always round. 2. The horizon is always a circle. If we are on a plain, our horizon is limited; if we ascend to a slight elevation, our view is more extended; and, if we go up a high mountain, we have still a wider horizon; but through all the changes our horizon is still a circle (see Fig. 64). This makes it quite certain that the earth is a sphere. 3.

FIG. 64.



Horizons of the Same Place, at Different Heights.

When vessels at sea come in view of an observer, we see first the top of the mast, then the upper sails; next the lower sails, and finally the hull. This is represented in Fig. 65, and shows conclusively that the surface of the ocean is spherical.

FIG. 65.

Proof of the Curvature of the Earth's Surface.

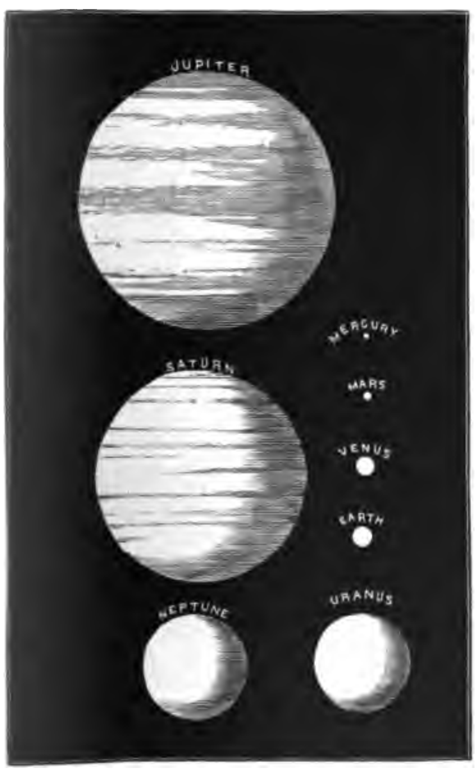
But the earth is not a perfect sphere. Her figure is flattened like an orange at the poles. Mathematicians describe the earth's figure as an "oblate spheroid." In order to understand some arguments made from these facts, the student is reminded of twirling a key, tied to

a string, in a circle round the hand. That the key has a tendency to move off in a straight line is shown at once when we let go the string. It is retained in place by the hand-grasp and the cohesive force of the string. If the string is not very strong, the motion may be rapid enough to break it. Now, there is a great deal of evidence to show that the earth was once in a semi-fluid or plastic condition from heat; that is, the earth was once revolving on its axis with the force of cohesion much weaker than it now is. Every particle moved, as now, in a circle like the key. The particles about the surface of the equator move most rapidly, since they move through larger circles in the same time. This increases their tendency to fly off, and to resist all forces of attraction; and, as cohesion was weak then, they pulled out the sphere about the equator, and thus the earth became an oblate spheroid.

The excess of matter about the earth's equator, and the attraction of the sun and moon for the parts nearest them, is said by astronomers to cause the precession of the equinoxes.

The planets in different degrees show this same peculiarity of figure; and, as will be seen, we have evidence that some of them are still plastic from heat. The polar diameter of Jupiter is five thousand miles shorter than his equatorial diameter.

FIG. 66.



Comparative Sizes of the Planets.

190. Volumes of the Planets.—The word volume refers to mere size, without regard to weight. Jupiter is the largest planet. His diameter is 84,000 miles, and his volume is thirteen hundred times that of the earth. Saturn comes next, with a diameter of 70,000 miles, and his volume is seven hundred times greater than that of the earth. The earth's mean diameter is 7,916 miles. The diameter of Neptune measures 35,000 miles, that of Uranus 32,000. Venus is a very little smaller than the earth in volume, and her diameter is only about 300 miles less than that of the earth. The diameter of Mars is about 4,000 miles, and his volume is about one seventh that of the earth. Mercury has a diameter of about 3,000 miles, and a volume about one sixteenth that of the earth. The diameter of the moon is a little more than 2,000 miles, and her volume is about one fiftieth that of the earth. These comparative volumes are illustrated in Figs. 66, 67, 68, 69.

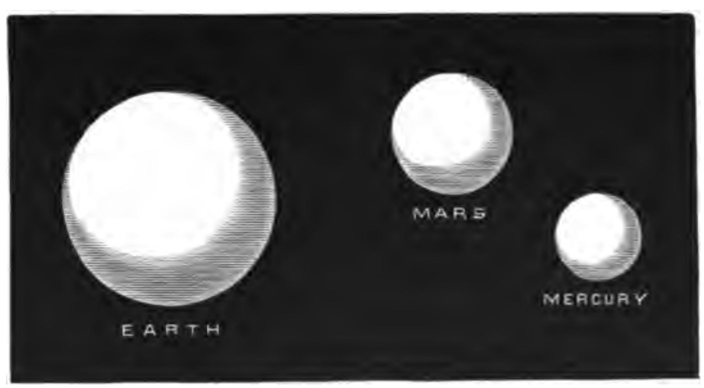
FIG. 67.

Earth and Moon.

191. Densities.—The density of a body is its weight in proportion to its size, or in comparison with an equal volume of some other body. Thus a pound of iron is denser than a pound of wood. The earth is about five and two thirds as heavy as would be a globe of water of the same size. The density of Mercury is about six fifths that of the earth; that of Venus is a little less than that of the earth. Mars has only three fourths the earth's density. Jupiter is lighter than would be a globe of water of the same size, while Saturn has half the density of Jupiter. Uranus is a little less dense than Jupiter, and Neptune than Uranus.

FIG. 68.

FIG. 69.

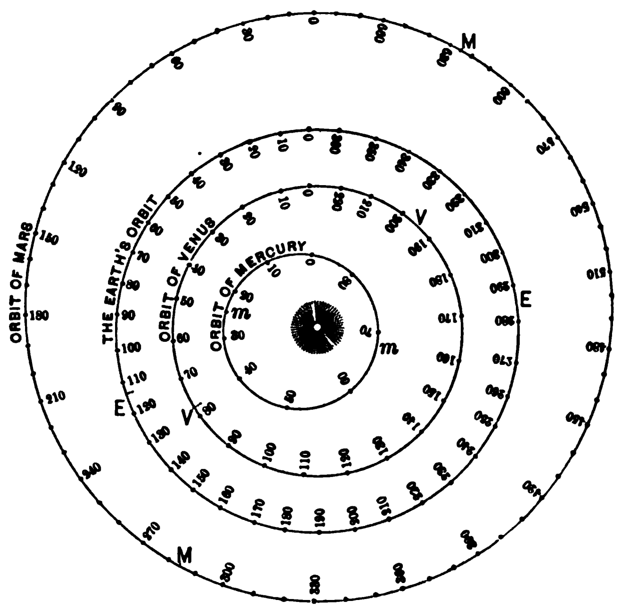


192. Eccentricity of Orbits.—The orbits are all ellipses. We know that the earth's orbit is an ellipse be-

cause the sun varies in apparent size; and we attribute this to a variation of his distance. The moon also varies in apparent diameter. So do the superior planets vary in diameter at different oppositions. The angle made by Venus and the sun at her greatest elongations varies in consequence of the varying distance of Venus from the sun, and the same is true of Mercury. All these facts show that the orbits are not perfect circles. Accurate measurement is, of course, required to ascertain the figures of the different ellipses.

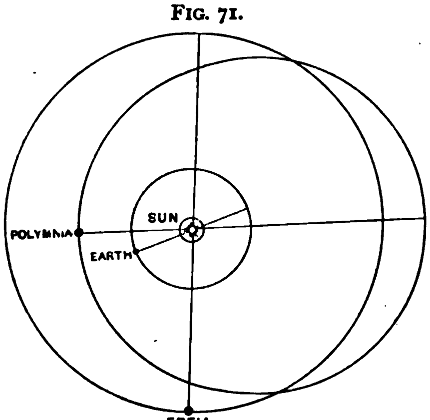
The eccentricity of an ellipse is the degree in which

FIG. 70.



it differs from a circle. The orbits of the earth and moon can hardly be distinguished from circles. That of Venus is the least eccentric of all. This is shown by the fact that the angle of her greatest elongation differs very little from 47°. The almanac always reports it. But the other inferior planet, Mercury, sometimes reaches 28° above the sun, sometimes only 17°. This makes it at times very difficult to see Mercury. Thus the two inferior planets, Venus and Mercury, have the least and the most eccentric orbits of any of the major planets. Mars comes next to Mercury. Every fifteen years he is much brighter at opposition than at the intervening oppositions. The orbit of Jupiter has about half the eccentricity of that of Mars.

FIG. 71.



The asteroids are remarkable for the very great eccentricity of their orbits.

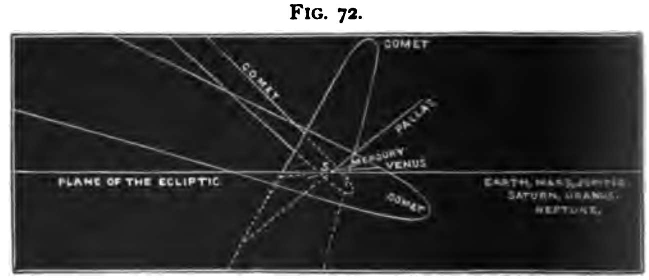
The orbits of some of the planets are illustrated in Figs. 70 and 71.

The orbit of Polymnia is the most eccentric orbit to be found among the asteroids.

193. Inclination of the Planes of the Orbits to the Ecliptic.—The ecliptic is the plane of the earth's orbit, as the student remembers. Also Mercury, Venus, Mars, and Saturn are to be looked for very near the ecliptic. This is because the planes of their orbits differ so little from the ecliptic. This subject becomes interesting as soon as we begin to watch the planets in nature. They are so near the great circle that we wish to know the exact angle made by the planes, since that marks their greatest distance from it. It must be remembered, however, that from the very fact that we are not in the same plane, we see them a little displaced from the positions in which an observer at the sun would see them. Uranus crosses the ecliptic at an angle of a little less than 1°; Jupiter, a little more than 1°; Mars and Neptune, less than 2°; Venus, a little more than 3°. Mercury wanders farther from the ecliptic than any major planet. He is sometimes 7° from it, and as the zodiac extends only 8°, he barely keeps within it. Mercury deals in extremes. He is the densest planet, the nearest to the sun, has the most eccentric orbit, and moves farther from the plane of the ecliptic than any other planet except the asteroids. Many of the minor planets are sometimes more than 10° from the ecliptic; and one, Pallas, gets as far as 34° from it.

Fig. 72 shows the angles made by the various planes

FIG. 72.



The Plane of the Ecliptic and the Planetary Orbits.

with the plane of the earth's orbit. A number of these differ from the ecliptic so little that they are not separately represented.

Distances from the Sun.

	Greatest distance—miles.	Least distance—miles.	Mean distance—miles.
Mercury,	43,000,000	28,000,000	35,000,000
Venus,	....	....	67,000,000
The Earth,	....	....	92,800,000
Mars,	153,000,000	127,000,000	140,000,000
Jupiter,	503,000,000	457,000,000	480,000,000
Saturn,	....	....	880,000,000
Uranus,	....	....	1,770,000,000
Neptune,	....	....	2,775,000,000

The moon is 240,000 miles from the earth.

Fig. 73, which shows the comparative size of the sun as he would appear to an observer on the different planets, enables the student to get a realizing idea of the distances from that luminary.

FIG. 73.

The Relative Size of the Sun, as seen from the Planets.

194. Sidereal and Synodical Revolutions.—When we are interested in observing the planets, we very soon become familiar with the meaning of a synodical revolution, since we learn from it when to look for any planet in the evening sky. The planets are evening stars through half a synodical revolution; morning stars through the other half. The synodical period of Mercury is 116 days; that of Venus, 584 days; that of Mars, 779 days, or 26 months; that of Jupiter, 13 months. The synodical periods of Saturn, Uranus, and Neptune differ so little from a year that they seem to come and go with the fixed stars.

The sidereal periods have an interest of another kind. The sidereal period of a planet is its year, containing an entire revolution of its seasons. These periods increase in length with the distances of the planets from the sun. They are as follows:

Mercury,	88 of our days.	Jupiter,	12 years (nearly).
Venus,	225 " "	Saturn,	29½ "
The Earth,	365¼ " "	Uranus,	84 "
Mars,	687 " "	Neptune,	165 "

195. Rotation of the Planets.—The planets all rotate on axes from west to east. We know this by the motion of spots or inequalities upon the surface. By the curves in which the spots move we learn the inclination of a planet's axis to the plane of the ecliptic, and from that we find its inclination to the plane of its own orbit. (See Fig. 55, page 57.)

Account of each Planet.

196. Mercury.—We know little of Mercury, owing to his great nearness to the sun. He seems to have a somewhat dense atmosphere, since, at the time of his transits over the sun, his dark disk has a dusky border or ring round it. Mercury is supposed to have no moons. He receives on an average seven times as much light and heat as the earth. But he must, at opposite points of his orbit, vary much in regard to both.

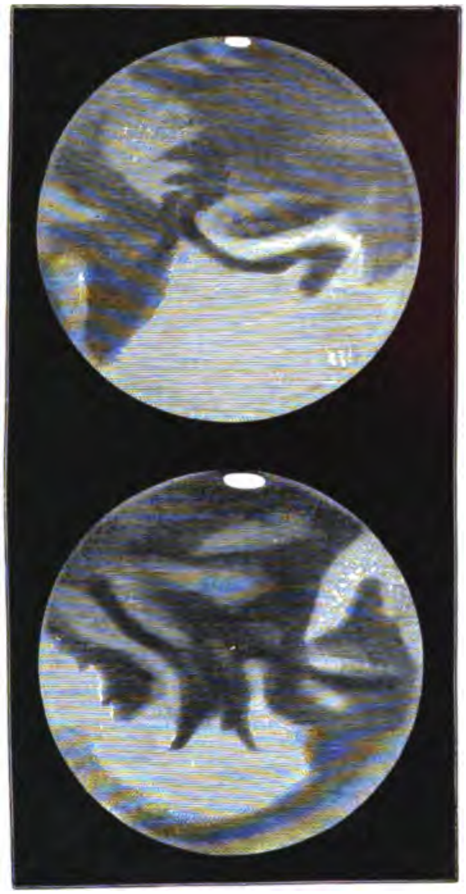
197. Venus.—We have the same reason for thinking that Venus has an atmosphere that has just been given in the case of Mercury. The vapor of water is found in her atmosphere. She resembles the earth in size and density, but receives twice as much light and heat from the sun. We know little of her.

198. Mars.—(Fig. 74.) In a very good telescope Mars appears to have his surface marked by what appear to be islands and continents of a dull-red color, and darker intervening spaces of greenish hue give the impression of water. By means of the spectroscope we find that there is certainly water in the atmosphere of Mars. There appears to be a great deal more land than water on Mars. The oceans are long, with narrow seas like canals

running up into the land, so that water communication must be very general on Mars.

At the poles there are white circles (probably ice-caps), which diminish in size when the sun is alternately turned toward them in the varying seasons of Mars. We have evidence that the axis of Mars is inclined to the plane of his orbit about as much as that of the earth is; and therefore the seasons must differ much as ours do, except that they are longer, in consequence of the greater length of the year of Mars, which is 687 of our days. The day of Mars is not far from twenty-four hours in length. The red color of Mars has been attributed to the cause which produces our sunset-red, viz., the absorption of certain rays by the atmosphere of Mars. But there are many speculations about it.

FIG. 74.



Mars in 1862.

The general appearance of Mars, the evidence of land and water, his seasons, his days, make him appear to be a globe similar to ours, and not unsuited to the support of life. But we have no evidence at all of its existence. Mercury, and especially Venus, come near us, but they are then so partially illuminated (being crescents) that we have no good opportunity to see their surface. Mars at opposition is near us, and in good position to be seen, since we see his side turned to the sun. He comes into this position only once in twenty-six months, but astronomers are then very assiduous in observing him. About every fifteen years he is still nearer. Much was learned in 1877, when he was at perihelion and the earth at aphelion, at the time of his opposition. Maps have been made of his surface.

Mars has two small moons, discovered in 1877 by Prof. Hall, and called Phobos and Deimos. The diameter of the inner moon, Phobos, is supposed to be less than ten miles in extent. It is only about four thousand miles from Mars. Our moon is about sixty times as far from the earth. Phobos revolves around Mars in a little less than eight hours, and, as Mars revolves on his axis in about twenty-four hours, it must move round Mars three times in the course of a Martial day. Phobos must rise in the west and set in the east. Deimos revolves about Mars in about thirty hours. Its diameter is thought to be less than forty miles.

199. **Jupiter.**—(See Fig. 75.) The axis of Jupiter is nearly perpendicular to the plane of his orbit, and therefore there can not be much variation of seasons.

From the small density of Jupiter, and the constantly varying character of his surface, it is believed that a large part of the planet that we see consists of an atmosphere filled with great clouds and heavy vapors. The changes are so great and sudden that it is supposed that heat must be the cause of such activity. We have abundant evidence that our own globe was once in a fluid condition from heat; and it is supposed that Jupiter is still in that situation, not having cooled off sufficiently to be covered with a solid crust. Belts formed of rolling clouds seem to stretch across the disk of Jupiter from east to west. At the equator, when not too strongly magnified, they have the appearance of two parallel belts. Parts of Jupiter show changes of color, putting on a rose hue between the belts.

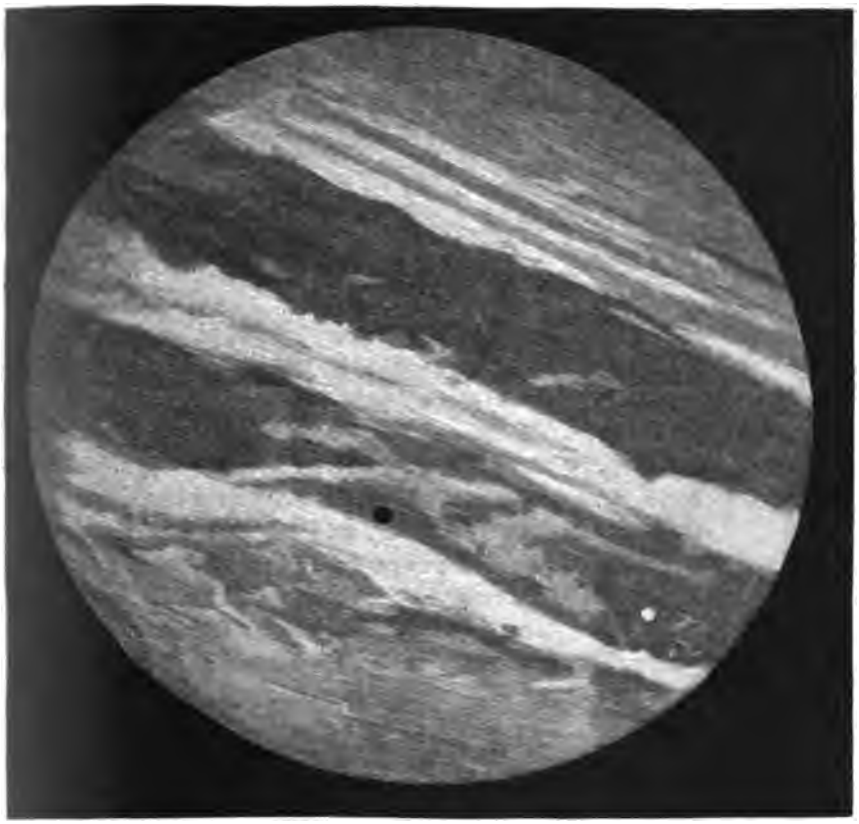
Jupiter, like the sun, is darker at the edges than near the center, so that his moons, when first seen passing over him, appear bright by contrast, but, as they approach the center, the contrast diminishes. There is some evidence that Jupiter has a little light of his own, but it must be small, since the moons do not reflect any of it when Jupiter is between them and the sun. Sometimes there are spots on Jupiter which pass away very slowly. In 1878 there appeared a great oval red spot not far from the equatorial belts, and it was seen at intervals for several years. There are indications that, in the case of Jupiter as in that of the sun, the equatorial parts rotate with a different velocity from the parts near the poles.

There is every reason to think that Jupiter is in no condition to maintain life; but he is of great interest to us, because he seems to be in the condition in which our earth was while undergoing the changes which fitted it to be the abode of men and animals.

Jupiter has four large moons. The largest has a diameter of about 3,700 miles, being nearly as large as the planet Mars. The smallest is about the size of the earth's moon. The shortest revolution around Jupiter takes a

little less than two days, and the longest nearly seventeen days. When Jupiter passes between his satellites and the sun, they are eclipsed and, of course, darkened. But

FIG. 75.



Jupiter can pass between us and his satellites without passing between them and the sun. They are then said to be occulted, because they are hidden from us; but they are not darkened.

When the moons pass between Jupiter and the sun they cast shadows on him. The bright side of the moon is turned toward us, and is seen to pass over the planet's face. This is called a transit of the moon. As we are not often in a straight line with the planet and moon, we usually see both the bright spot and the shadow. (See Fig. 75.)

The axis of Jupiter is very little inclined to the plane of his orbit, and the orbits of his moons are very nearly in the plane of his equator, so that they are all, except one, eclipsed at every revolution. If there were an observer on Jupiter, he would see in a year over four thousand eclipses of the sun, and about the same number of eclipses of the moon.

The moons of Jupiter can be seen through a very small telescope.

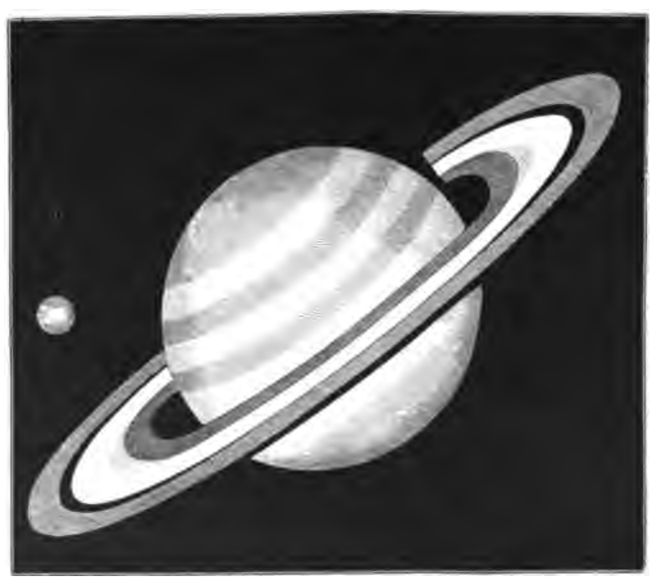
200. Saturn.—The axis of Saturn is much inclined to the plane of his orbit.

The telescopic appearance of Saturn has long been of great interest on account of his ring. Figs. 76, 77, give pictures of Saturn and his ring. The ring is thin and flat, and lies on the plane of Saturn's equator. It consists of three parts: 1. A dusky ring nearest the planet, and therefore in a position where it can not reflect much sunlight upon us. It is therefore difficult to see it. The outline of the planet has been seen through this interior dark ring. 2. Next to this dusky ring there is a bright ring. 3. Outside of this bright ring, there is another, not quite so bright, but still brighter than the dusky ring; and between the two outer rings there is an open space which is black in the picture. The inner edge of the ring is about twenty thousand miles from the planet. The ring is in motion round the globe; and, with the axis, is inclined about 27° to the plane of the planet's orbit. In moving, both axis and ring keep this inclination.

The rings of Saturn are now generally believed to consist of a multitude of small satellites so close together that, like a swarm of bees, they seem at a distance to be continuous. In the dusky ring, the particles are supposed to be farthest apart. The interior dark ring is sometimes called "the crape ring." The diameter of the outermost ring is more than one hundred and fifty thousand miles.

From the movements of Saturn and the earth, his

FIG. 76.



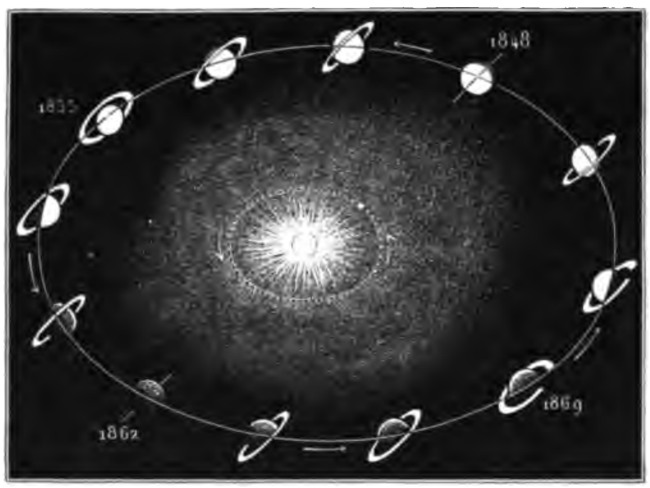
Saturn and the Earth—Comparative Size.

ring is turned in a great variety of positions as regards the observer. These are called the phases of the rings, and they are shown in Fig. 78. The rings and their phases may be seen in a telescope of small power, but a good view of the three rings can be had only in a telescope of high power. As Saturn is 29½ years in making a complete revolution round the sun, he takes the whole period to show all the phases. At two opposite points in Saturn's orbit, the ring is turned edgewise toward us, and then it disappears, except in the most powerful telescopes; and in them it looks like a thin line of light. The satellites of Saturn are nearly in the plane of the ring, and when it has this appearance they are seen moving on its edge "like golden beads on a silver thread." The disappearance of the ring shows its very great thinness. This phase is shown in Fig. 79.

FIG. 77.

Saturn with the North Surface of its Rings presented to the Earth.

FIG. 78.



Different Appearances of Saturn's Rings.

FIG. 79.

Appearance of Saturn when the Plane of its Rings passes through the Earth.

Saturn's sphere seems to be very much in the condition of Jupiter. It is covered with clouds in which some faint traces of belts are distinguished, and is probably still hot and the seat of great activity. But Saturn is so far away that it is difficult to know much about him.

Saturn has eight moons. The largest of these, Titan, is larger than the planet Mercury, and can be seen in very small telescopes. But they are not all visible except in telescopes of the largest size.

201. Uranus and Neptune.—Nothing is known in regard to their physical features. In a large telescope, Uranus is said to have a sea-green appearance. Uranus receives $\frac{1}{370}$ as much light and heat as the earth; while Neptune receives only $\frac{1}{1000}$ as much.

Uranus has four moons, whose orbits are inclined nearly 80° to the plane of the planet's orbit. Neptune has one. The satellites of Uranus and Neptune have one remarkable peculiarity: they revolve around their planet from east to west; all other planets and satellites revolve from west to east.

202. The Moon.—That the moon has no appreciable atmosphere is clearly shown in several ways. At half-moon, the diameter which forms one boundary is the dividing line between day and night on the moon. If there were an atmosphere, there would be some indication of twilight near this line; but there is none. The shadows of the mountains are pitchy black, showing no trace of the diffused light which would result from an atmosphere. Besides, if the moon had any atmosphere, we should expect, at a solar eclipse, that her edge would be surrounded by a dusky ring or border, such as are seen around Venus and Mercury when making a transit across the sun's face. But there is nothing of the kind. Also, in the moon's course through her orbit, she often passes over or *occults* a star. If she had any atmosphere, we should probably see these stars become dimmed just before disappearing; but they seem suddenly blotted out. Astronomers have made careful observations to see whether there were any traces of refraction. The conclusion is, that the moon has no appreciable atmosphere.

FIG. 80.

Moon at the First Quarter. (From Photographs taken by Prof. H. Draper, New York.)

There never is any appearance of clouds passing over the moon, except clouds near the

FIG. 81.

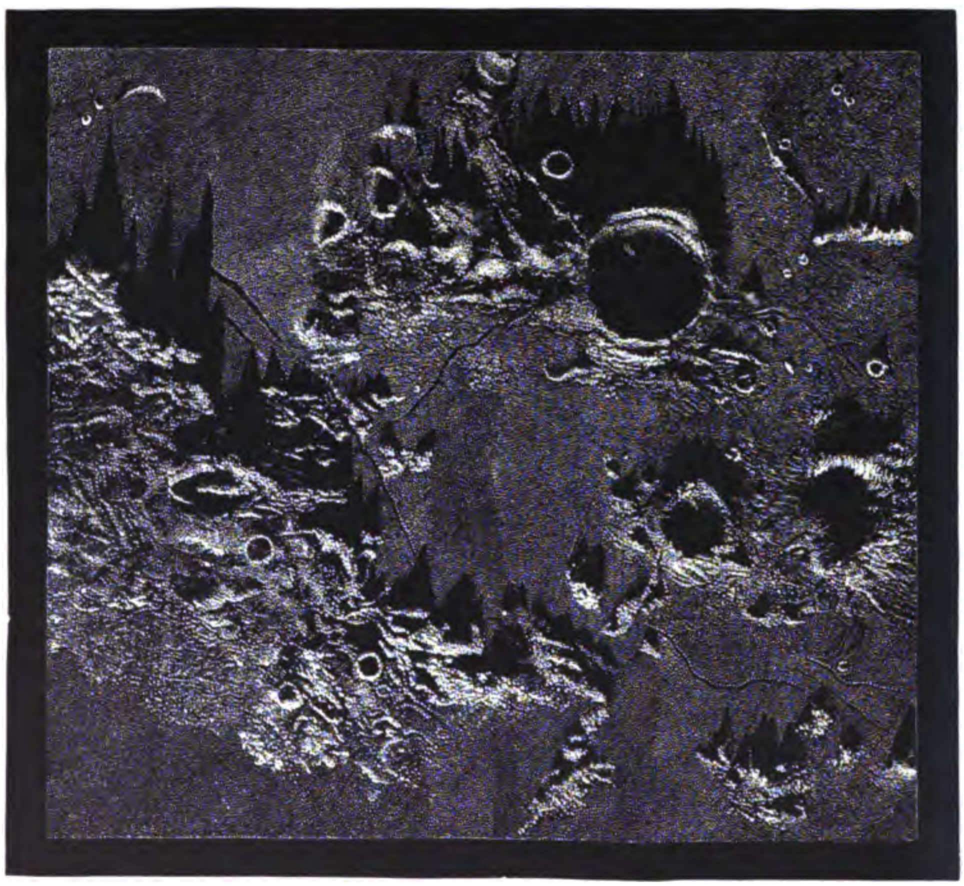
Moon Scenery.

earth. There is, thus far, an absence of indication of water.

The moon's surface, to an observer with the naked eye, seems spotted with dusky patches, in which imagination sometimes sees a resemblance to a human face popularly called "the man in the moon." Under a telescope of low power, the dusky patches appear smooth, but with higher power, elevations and depressions become visible. The moon's face seems to be thickly pitted with the craters of extinct volcanoes. Many of them have central cones which have every appearance of having arisen from eruptive action, which would have great power on the moon, since the force of gravity would be less than on earth, owing to the moon's smaller mass. Some of the craters are, however, different from those of any volcanoes that we know, appearing to be mere plains surrounded by irregular circular walls. In the formations on the moon there is a very general tendency to circular shape. The greater number of the craters are depressed below the surface, but some are hollowed out in elevations. In some places they stand singly on the plain; in others they are crowded and heaped upon one another; sometimes there are small craters on a plain which is surrounded by the wall of a large crater. They are of all sizes, from the small one just visible to us, to the great one with a diameter of a hundred and fifty miles. The great crater Ptolemy incloses a space equal to the State of Massachusetts. These formations are generally regarded as due to volcanic origin, but it is not believed that there are now any active volcanoes on the moon. The moon has been compared to a burned-out cinder.

The inequalities of the moon's surface are best shown at or near her quadrature. The line which separates light from darkness is called the *terminator*. On this line the sun is all the time rising or setting, and therefore long shadows are thrown which bring out details and show the heights of mountains. (Something of this irregular appearance of the terminator can be seen at quadrature without a telescope.) Besides this, there are elevated portions which catch the light both before sunrise and after sunset. These effects can be seen very plainly with a telescope of even moderate power. Fig. 80, showing the shadows, and also the light on the

FIG. 82.



Moon Scenery.

elevated points, is a reduced copy of one of Rutherford's photographs of the moon.

There are also chains of mountains on the moon.

FIG. 83.

Moon Scenery.

Their heights have been ascertained by means of their shadows; and it is found that in proportion to the size of the moon, her mountains are higher than those on the earth. There are chains which have been named respectively the Alps, the Apennines, and the Caucasus. Fig. 81 shows the region of the lunar Alps, with the great crater Plato. The diameter of Plato's ring is about seventy miles, and the mountains surrounding it are five or six thousand feet high. To the left of Plato there is a remarkable valley, the valley of the Alps. It is as level as if it were a roadway made by engineers; but it is bounded by very tall mountains. It is six miles wide and seventy-five miles long. The sun is on the left of the picture, and the mountains throw long shadows on the right.

Fig. 82 is a representation of the lunar Apennines and the great crater Archimedes. These mountains rise to nearly eighteen thousand feet. On the plain there are black lines representing the chasms, cracks, or canals, which form a curious feature of the moon's surface. Some of them are a hundred miles long, and some are known to be eight miles deep. They are supposed to be of volcanic origin.

Fig. 83 shows an ideal lunar landscape, taken from the work of Nasmyth and Carpenter on the moon.

There is another very curious feature of the moon's surface seen when she is full, and when, of course, the perpendicular rays of the sun shine on her. There are seen, radiating from some of the craters, bright streaks, which run over the surface of the moon for hundreds of miles, crossing mountains and valleys without seeming to be stopped by any obstacles whatever. Fig. 84 shows the full moon and these bright streaks. They radiate especially from three great craters, Tycho, Copernicus, and Kepler. They do not appear to be elevations or depressions on the moon's surface. It has been well said, "They look as if, after the whole surface of the moon had received its final configuration, a vast brush charged with a whitish pigment had been drawn over the globe, leaving its trail upon everything it touched, but obscuring nothing." An effort has been made to account for these appearances by supposing that the moon, in cooling, suddenly cracked; that these cracks afterward became filled with melted lava, which, when cool, presented a smooth surface capable of reflecting light. This, of course, is not much more than conjecture.

FIG. 84.

Full Moon. (From Photographs taken by Prof. H. Draper, New York.)

It is supposed that the moon represents a body like the earth, in a much more advanced stage of cooling than the planet on which we live. It has, astronomers think, reached the stage when it can no longer support any form of life that we know.

CHAPTER X.

METEOROIDS AND COMETS.

203. **Shooting-Stars.**—When we are out of doors after dark on a clear evening, we frequently see what appear to be stars moving swiftly across the sky and vanishing; sometimes leaving, for a few seconds, a long train of light, and sometimes breaking into pieces without any noise. These bodies are called *shooting-stars.*

204. **Meteors.**—Occasionally we see larger moving bodies giving a brilliant light, which in some instances is bright enough to illuminate the whole heavens. Some of these explode with a loud noise. These larger shooting-stars are commonly called *meteors*, though the name applies in strictness to both classes.

205. **Aerolites.**—Besides this, stony or metallic bodies are, at rare intervals, known to fall through the air, penetrating a short distance into the earth, and being hot if found soon after the fall. A very few of these stones are large bodies. One in the cabinet of Yale College weighs nearly a ton. Sometimes they fall in numbers. These falling bodies are called *aërolites.* They are composed of chemical elements well known on earth, but sometimes in combinations not seen here except under circumstances which furnish good evidence that they have fallen from the skies.

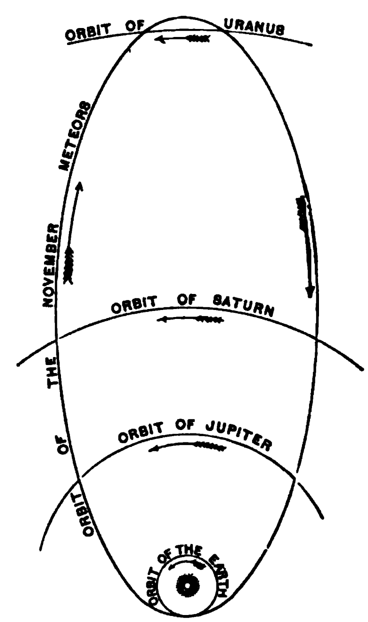
206. **Composition.** — It is now believed that these bodies can be distinguished by their composition when there is no other evidence of their fall. They always contain iron in the metallic state, which is very rarely found on earth. They are called meteoric iron and meteoric stones, according as they are composed largely of metallic iron, or as they contain a larger proportion of other elements. They also have in them compounds of iron not known on earth. Meteoric iron has a crystalline structure, and aërolites in general look as if they had been melted to some distance below their surfaces.

207. **Origin.**—It is now thought that a large number of small particles and masses of matter revolve round the sun, and, coming within the sphere of the earth's attraction, they are brought into forcible contact with our atmosphere. The collision produces heat and sometimes light, and in some cases the effect is great enough to produce explosion. The atmosphere is very attenuated matter, but the velocity is so great that the result is like that of striking flint with far less velocity.

To these bodies, called meteoroids, are due shooting-stars, meteors, and aërolites, which thus all belong essentially to the same class. Meteoroids are supposed to be exceedingly numerous. It has even been estimated that eight million pass through our atmosphere in twenty-four hours. The visible path of shooting-stars is usually between fifty and seventy-five miles from the earth.

208. **Meteoric Showers.**—There are also periodical showers of shooting-stars. About November 13th there is a noticeable shower every year. The meteors seem to radiate from the constellation Leo, and therefore they are called the Leonids. The radiation is apparent. The small bodies move in parallel lines, and they seem to diverge from Leo because all parallels seen a long way off appear convergent. The orbit of these meteors is exhibited in Fig. 85. They evidently move in their orbit retrograde, or from east to west. There must be a distribution of meteors along the whole line, since they are seen every year, but every thirty-three years there is an unusual exhibition of them, and therefore it is supposed a great number are collected in one part of their orbit. The earth crosses this orbit every year, but only encounters the great body of meteors every thirty-three years, because that is their period of revolution. In 1833 there was a striking display of these meteors in the United States. The sky was covered with lines of light in every direction, and great alarm was excited among ignorant people. The last great exhibition occurred in 1866, but it did not equal that of 1833. It is supposed that the dense mass is of such extent that the earth gets into some part of it for three successive years. There was a lesser recurrence of the shower of 1866 in the two following years. The November meteors do not generally explode. They are small bodies.

Fig. 85.



Another annual shower of less brilliancy comes in August, and, as these seem to radiate from the constellation Perseus, they are called the Perseids. It is supposed that the earth passes through the orbit of the Perseids in August. Since there is no variation in different years, it is supposed that the Perseids are pretty regularly distributed along their orbit. The perihelion points of the orbits of both Leonids and Perseids touch the earth's orbit. The orbit of the August meteors reaches far beyond Neptune, and it is thought they take one hundred and twenty years to make a revolution.

There are other meteor groups, but these are the most important and well known.

Comets.

209. Description.—When comets are first seen with the telescope, before they come near enough to be visible to the naked eye, they look (as do the nebulæ hereafter to be described among the fixed stars) like small clouds. They can be distinguished from the nebulæ only by their motion. There are many comets called telescopic comets, because they can not be seen by the naked eye. Their approach to the sun makes them large and conspicuous. In order that we may see them, especially with the naked eye, their nearest point to the sun must be not very far from the earth's orbit.

Fig. 86.

Comet of 1264.

210. Parts of Comets.—Comets which can be seen without a telescope have, when near the sun, three parts. They have a nucleus, which is very like a bright star, and which is surrounded by a cloudy, shining envelope called their Coma. They have also a tail, which is a long stream of light extending from the coma (see Fig. 86). Their approach to the sun develops these parts. As they draw near that luminary, they throw out jets toward the sun which seem to be alternately attracted and repelled by him. The appearances are very like those exhibited by bodies in opposite states of electricity. It has also been noticed that large comets in the neighborhood of the sun throw off from the jets, toward the sun, a succession of apparently vaporous envelopes. These were observed with great care in the case of Donati's comet, which appeared in 1858. Fig. 87 shows these envelopes. Donati's comet was one of the most brilliant of modern times (see Fig. 88). It came so near the earth's orbit that, had the earth been on the same side of the sun, it must have passed through the comet's tail. The same envelopes were seen in Coggia's comet in 1874.

Fig. 87.

Donati's Comet (showing the Head and Envelopes).

Fig. 88.

Donati's Comet (general view).

211. Tails of Comets.—As comets draw near the sun, their tails are developed with great rapidity on the side turned away from the sun. Thus, when approaching the sun, the tail follows the nucleus and coma, but in receding from the sun the nucleus and coma follow the tail. The tails of comets are of very various lengths, some extending more than half across the heavens above the horizon. Their tenuity is very great, very faint stars being seen through them. The earth is believed to have passed through the tail of a comet in 1861, without the fact being known to its inhabitants. This was a very brilliant comet, fan-shaped. It is shown in Fig. 89. The comet of 1744 had five tails (see Fig. 90).

Fig. 89.

Comet of 1861.

212. Origin of Comets.—Comets are supposed to come from the stellar spaces beyond the solar system, and to be drawn into the sphere of the sun's attraction. Some

move in ellipses and are called periodical comets, since they return; while others appear to move in curves

FIG. 90.

Comet of 1744.

which do not reach the point from which they started.* Whether the figure is an ellipse depends on its velocity in proportion to its distance from the sun. Where the ratio of the velocity to the distance is small, the figure is an ellipse, and the degree of eccentricity of the ellipse depends upon the same proportion. But comets are apt to have their speed increased or diminished by the attraction of the planets which they pass, and thus their orbits become changed. The attraction of the greater planets produces decided effect in changing the orbits of the comets to ellipses. In that case the aphelion points of their orbits are found not very far from the orbit of the planet. There are a number of comets thus connected with each one of the larger planets.

213. Return of Comets.—The first comet of which the return was successfully foretold is called Halley's comet. He saw it in 1682, and found that its orbit was about the same as that of two comets which had previously appeared, one in 1531, the other in 1607. The orbit of the latter had been investigated by Kepler. The comet made its appearance a little later, but it was shown by another astronomer that its delay was occasioned by the attraction of Jupiter and Saturn. It was shown to be identical with a comet seen and recorded in 1066, 1456, and 1531. It returned, according to Halley's prediction, in 1759, and was last seen in 1835, when it was very brilliant and excited great interest. In 1456, it caused much alarm, as this was soon after the Turks took Constantinople and threatened the rest of Europe. It was this comet that caused the prayer, "From the comet, the Turk, and the devil, good Lord, deliver us." It was 60° in length, and was thought to resemble a saber.

* These curves are known to the students of conic sections as parabolas and hyperbolas.

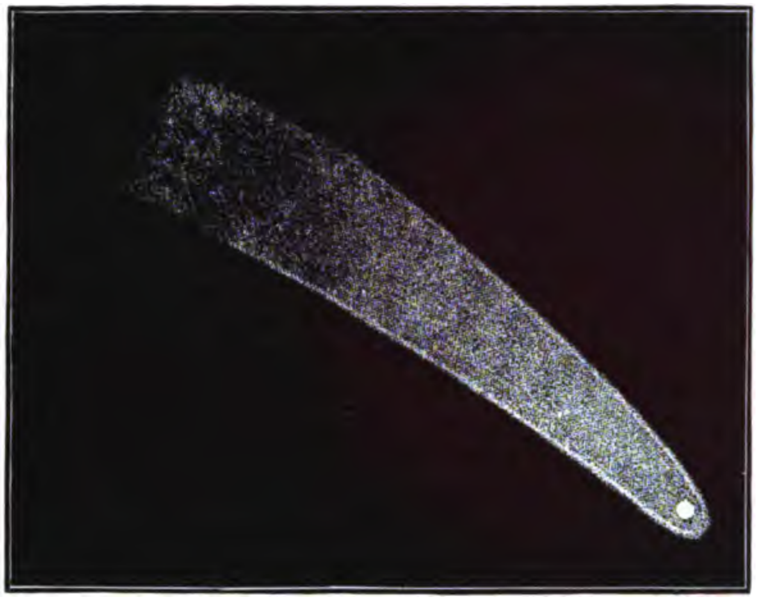
214. Meteors and Comets.—There are a number of facts showing a close connection between comets and meteors. There is a comet which has the same orbit as the November meteors, while another has that of the August meteors. Biela's comet furnishes further evidence of this relation. This is a periodic comet, and when it came again in 1845 it was found, after its appearance, to have divided into two parts, of which one disappeared before the other. In 1852 both returned, and were found still farther apart. After their disappearance, they were not again seen. But, in 1872, the comet was due, and on November 27th, the time when the earth's orbit crosses that of the comet, there was a great shower of meteors, which seemed to come from the part of the sky where the comet would have been situated. (See Note, p. 74.)

It is thought that the nucleus of a comet may consist of a collection of meteoroids. Through some telescopic comets, stars can be seen, and in this case the meteoroids must be small and far apart. But in large comets they must be very dense, if the nucleus is not solid. The tail and coma are produced by vaporization as they draw near the sun. In 1843 there was a very brilliant comet clearly visible. Its tail stretched through 65°. It passed very near the sun, being within his exterior atmosphere, and, while thus near, passed half round the sun in two hours, revolving its tail through 180° in that short time. From this it would appear that the matter of which the tail is made is all the time changing, like that of smoke from a chimney or vapor from a kettle.

215. Comets and the Spectroscope.—Comets have been examined in the spectroscope; the brilliant comet of June, 1881, being subjected to thorough study. They show a spectrum in which are indications of hydrocarbon vapors. Their light is probably due partly to reflection of the sun's light, and partly to these vapors when acted upon by an electric discharge passing through them.

216. Numbers of Comets.—There have been about five hundred comets seen by the naked eye since the beginning of the Christian era. About two hundred telescopic comets have been seen since the instrument was invented. Doubtless a much larger number has existed beyond the limits of our observation, which are very narrow. There are accounts of comets in ancient times, but the description is so colored by the alarm they excited that it can not be trusted. There was a great comet visible before the assassination of Julius Cæsar, 43 B. C. It was seen for several hours before sunset. It was supposed by Halley to be the same

FIG. 91.



Comet of 1811.

comet which appeared in 1680, when its orbit was investigated by Sir Isaac Newton. A very remarkable comet was seen in 1811, just before the invasion of Russia by Napoleon Bonaparte. It was very brilliant, and was seen for seventeen months. (See Fig. 91.)

217. The Zodiacal Light.—If, on a clear evening in late winter or in spring, we look, just at the close of twilight, at the part of the horizon at which the sun has set, we may see a sort of aurora of faint pearly light, of a half-oval figure, with its base resting on the horizon, and its axis coinciding with the ecliptic. It is visible for nearly 90° from the sun, growing fainter as the distance from him increases. It is represented in the wood-cut, Fig. 92. It is a lens-shaped appendage surrounding the sun and lying nearly in the plane of the ecliptic. It is called the Zodiacal Light.

The zodiacal light is also visible in the autumn at the beginning of the morning twilight. It is seen at evening on or near March 21st, and in the morning on or near September 1st, because at those seasons and hours the ecliptic makes its greatest angle with the horizon. At other seasons, when the ecliptic makes a smaller angle, the zodiacal light is so near the horizon that it can not clearly be distinguished, and also it sets before the sunlight has entirely faded. People who live within the tropics, where the air is very clear, can sometimes trace it entirely across the sky from east to west.

It sometimes obscures very small stars within its area on the heavens.

Various explanations of the zodiacal light have been suggested. Some observers have supposed that it might be an extension of the sun's corona. The most common opinion now attributes it to a collection of very minute meteoroids revolving about the sun nearly in the plane of the ecliptic and reflecting his light. When the zodiacal light is visible, it marks the course of the ecliptic very clearly.

FIG. 92.

NOTE.—Biela's comet had a period of 6⅝ years. It would have been due in 1879, but neither comet nor meteors were seen. In November, 1885, it was again due. While this book is going through the press, there are received full accounts from observers in various parts of the world. The comet was not seen, but on the nights of November 25th, 26th, 27th, there was a brilliant meteor-shower radiating from Andromeda and reaching its maximum on November 27th. It was best seen in the eastern part of Europe, though visible in the United States. It is now regarded as nearly certain that Biela's comet has broken up into a collection of meteoroids revolving around the sun.

PART III.

THE HEAVENS OUTSIDE OF THE SOLAR SYSTEM.

CHAPTER XI.

218. The stars are usually divided into fixed stars and planets. The latter class includes the stars revolving round the sun, both primaries and secondaries, or moons. All other stars were called *fixed stars*, because they showed no change of place as regards each other, though they all revolve round the earth.

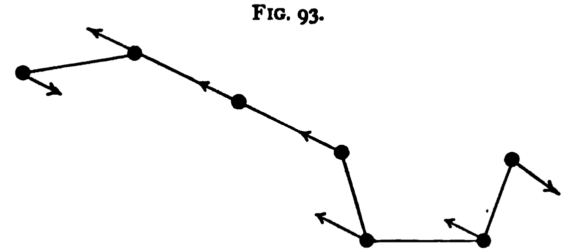
219. **Movements of the Fixed Stars.**—The ancient astronomers at Alexandria ascertained with some accuracy the relative positions of the chief fixed stars, and, in the early part of the last century, Halley compared the records left by them with the results of observation, and he was led to believe that the so-called fixed stars have changed relative place. Owing to their enormous distances from us, we perceive this motion very slowly, and so it was only detected by the combined work of men living many centuries from each other. Other astronomers began to investigate the subject. Finally, they came to the conclusion that the stars examined seemed all to be moving farther from a point in Hercules, and nearer to a point of the celestial sphere situated exactly opposite Hercules, or 180° from him. This is exactly the appearance which would be produced if our sun were moving toward Hercules, carrying with it all the bodies dependent on it. Thus they were led to think it probable that the sun has a real motion. This motion, called the *Secular Motion of the Sun*, appears to be very slow, only because it is measured by bodies at such enormous distances from us.

220. **Secular Motion of Stars.**—Besides these changes of place, which could be explained by the supposition that we ourselves, with the solar system, are in motion, there were others which could not be thus accounted for, and they led to the belief that the stars have a very slow real motion of their own, which is called the *Secular Motion of the Stars*. The slowness of the motion is apparent, resulting from the enormous distance of the stars. The student who has seen a train of cars moving at a very great distance remembers that they seem to creep over the earth. On the other hand, a traveler may move rapidly for a whole day, but, if he measured his motion by a far-distant mountain only, he would not see that he had changed place.

After the invention of the spectroscope, it was used in studying this problem. The displacement or bending of lines toward the red or the violet end of the spectrum indicates motion toward or from the observer. The results in regard to the motion of the stars confirm the previous conclusions.

221. **Star-Drift.**—It is found that stars in certain parts of the heavens have motions in a common direction. Mr. Proctor, who has specially studied this subject, proposes for this motion the name of *Star-Drift*. Thus five stars in the Great Dipper have a common motion in the same direction, while the two others move in another direction (see Fig. 93). This must, in the course of ages,

FIG. 93.



alter the figure of the Great Dipper. The spectroscope confirms these conclusions by showing that these five stars recede from us.

222. **Motion of First-Magnitude Stars.**—It will interest students to know that, of the first-magnitude stars, Sirius, Regulus, Betelguese, and Rigel are found by the spectroscope to be receding from us, while Arcturus, Vega, and Pollux approach us. The rates of motion even are computed, but the results are not more than an approximation. The spectroscope, the student must remember, only tells about approach toward the observer or recession from him, but nothing as to the general direction. A little reflection about motions of persons (or bodies) whom he sees on earth will make the student understand that they may move in many different directions, any one of which might make them draw near us or recede from us.

Nothing, therefore, can at present be known, from the observed facts, in regard to the figure of the sun's motion, or that of the stars. The epithet *fixed* stars is still used for distinction.

223. **Physical Constitution of the Stars.**—The spectroscope shows that they resemble our sun. They all show the dark Fraunhofer lines, and thus it is evident that the luminous spheres are enveloped in vapors absorbing the light from some of the rays. The lines show that

they contain elements known to us, and existing in our sun.

The spectra of different stars vary somewhat. They have been arranged in four classes. The stars vary in color, as any observer may see. Thus, Antares and Aldebaran are red; Vega Lyræ, Altair, and Spica Virginis are pale blue; Capella and Sirius are white; Arcturus, Pollux, and Procyon are yellow. The colors are due to vapors in their atmospheres cutting off part of the light, and the colors generally mark different classes of stars. The yellow stars are more like our sun.

224. Distances of the Stars.—For a long time it was thought that no fixed star showed any apparent change of place, due to the earth's change of position, in six months, between points 185,000,000 miles apart. But refined and accurate instruments and methods of observation have shown that some of the stars exhibit a very small displacement, not in any instance amounting to 1″. The star *α Centauri* has a pretty well-ascertained parallax, and is supposed to be the nearest of the fixed stars to us. But the distance must be about twenty billions of miles. These numbers convey little idea to us, and it will perhaps give a more definite notion to the student if he is told that it would take light more than three years to reach us from *α* Centauri. The other stars are probably nearly all much farther from us.

225. Magnitude of the Stars.—None of the fixed stars show any disk even when examined with the most powerful telescopes. This is one way in which observers with the telescope readily distinguish planets from stars. The telescope aids us in observing a star merely by its power of collecting light. It does not magnify the stars, as they are too far off. Therefore, we know nothing of their magnitudes.

226. Numbers of the Stars.—Observers with the naked eye see about five thousand stars. With the great telescopes of modern times they see many millions, but no estimate has been made approaching exactness.

227. Double and Multiple Stars.—Some stars which are single to the naked eye are resolved by a telescope into two or three or sometimes more stars. In some cases, this is due to the fact that stars not near together are on the same line of vision, and in such cases they are called *optically double stars*. But in many instances, it is found that these stars are connected by revolving around a common center; and in that case, they are called *physically double stars*. The motion, and even the period of some stars is clearly determined, as in *ξ* of the Great Bear, which completes a revolution in sixty years. *ε* Lyræ can be resolved into a double star by a good opera-glass (young people with good eyes see it double without a glass), and a powerful telescope shows that each of these stars is double. (See Figs. 94 and 95.)

FIG. 94.

Orbit of a double Star.

FIG. 95.

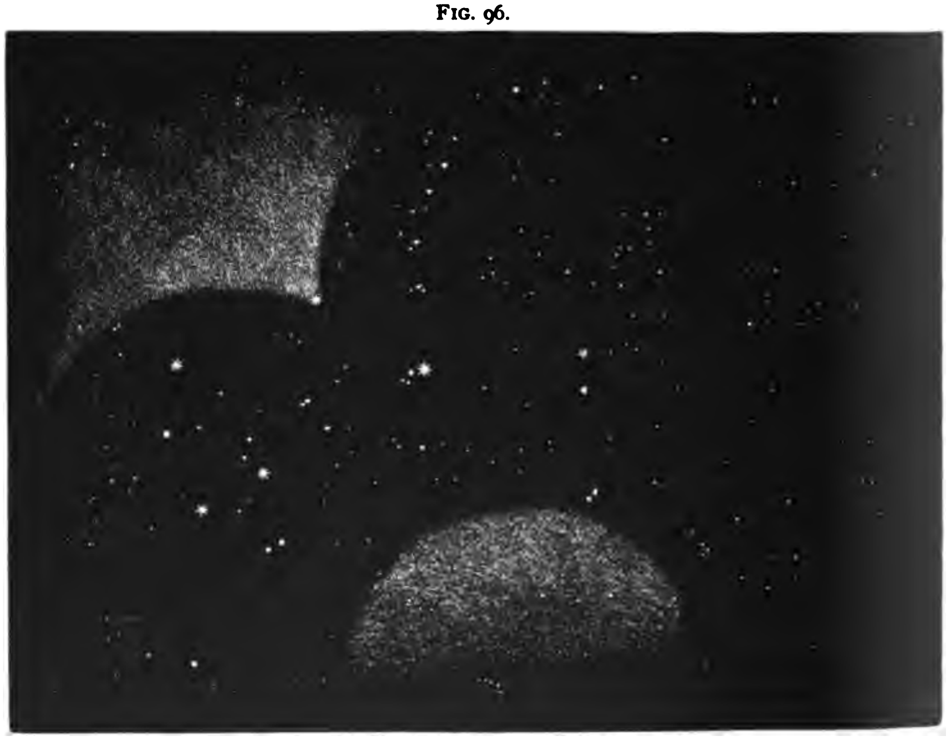
The double-double Star in the Constellation Lyra. 1. As seen in an opera-glass. 2. As seen in a small telescope. 3. As seen in a telescope of great power.

Double and multiple stars are very often of different colors, and sometimes of complementary colors.

228. Variable Stars.—This name is applied to stars which have periodical variations. There are many of these. The most noted of them are the stars Algol or *β* Persei; Mira in Cetus, or the Whale; and Eta, or *η*, in the ship Argo.

The changes of Algol, or *β* Persei, are of such short period that any observer may detect them if he knows

FIG. 96.



The Pleiades in a large Telescope.

when to look for them. Algol occupies seven hours out of every sixty-nine in making a gradual change in luster or brilliancy. Algol is usually a faint star of the second magnitude, but during twenty minutes at the middle of the seven hours, it becomes a star of the fourth magnitude. The change is very gradual. In order to remark it, it is necessary to compare Algol, before the beginning of the variation, with some other star of the same size. This gives a standard by which to observe the change. The exact period in which the variations of Algol are completed is two days, twenty hours, forty-nine minutes.

Mira in the Whale, or *o* Ceti, as the star is called by astronomers, is a star whose variations can be seen with the naked eye. It has a period of nearly a year. From a star of the second magnitude it becomes invisible. Its variations are not altogether regular.

Eta, in the ship Argo, or the star η Argus, is variable. This is a star of the southern hemisphere. It was seen by Sir John Herschel brighter than any other star except Sirius, and he says it then began to decrease and passed slowly out of sight.

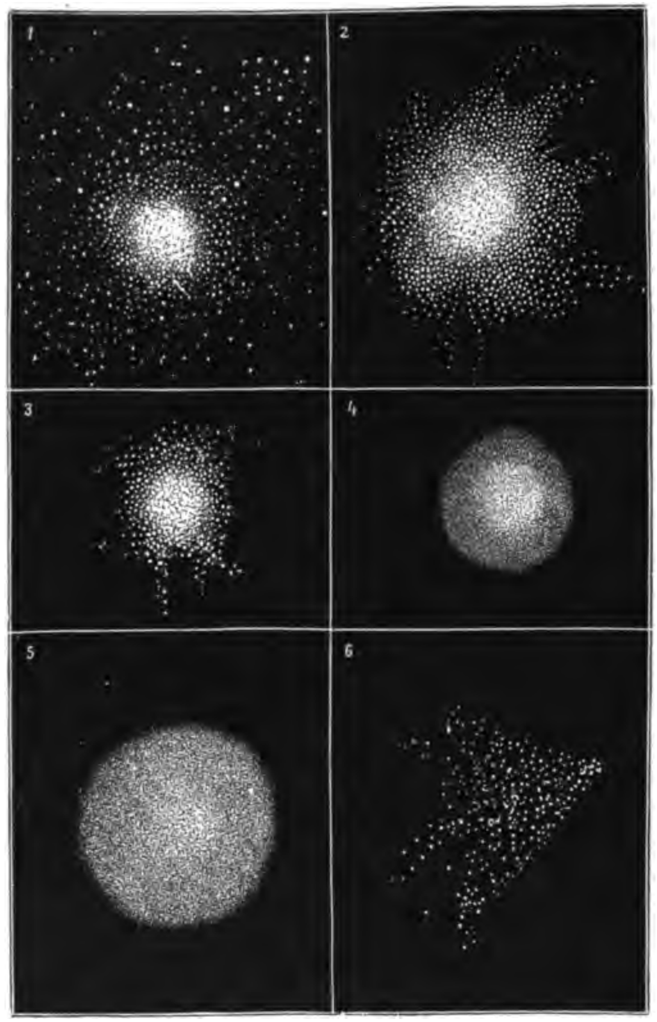
229. New Stars.—There are some instances of stars which have suddenly appeared and shone for a time with great brilliancy, disappearing afterward. In the year 1572, such a star appeared in the constellation Cassiopeia, and was described by the astronomer Tycho Brahe. It outshone Jupiter and Venus, and could be seen at noon. After six months, it disappeared, and has not been heard of since. It underwent several changes of color while visible. In 1604, a new star of the first magnitude appeared in the constellation Ophiuchus. It was visible more than a year, and then disappeared. This is sometimes called Kepler's star, because this astronomer observed and recorded its changes and appearance. In 1866 a telescopic star in Corona Borealis suddenly increased to the second magnitude and afterward faded. It was examined with the spectroscope and gave evidence of a conflagration in which hydrogen was the chief agent. The red flames of the sun's chromosphere are due to hydrogen, and it is supposed that this star showed phenomena like the red prominences, only on a much larger scale.*

230. Star-Clusters.—The Pleiades are a cluster of stars. The ordinary observer sees six stars; good eyes sometimes detect seven; a small telescope brings out many more; and one of the large telescopes shows over five hundred. (See Figs. 96, 97.) The telescope shows fine globular clusters in Hercules, in Aquarius, and in Toucan, in the southern hemisphere. One of the finest is in Centaurus. In the sword-handle of Perseus, there is a star which appears hazy to the naked eye, but a telescope of moderate power shows that it is a very brilliant cluster.

* See note at the end of Chapter XI.

231. The Galaxy, or Milky-Way.—This has been described in Chapter I. When examined through the telescope, it is seen to be composed of very small stars whose combined light creates the milky appearance. It contains many clusters of stars. The numbers of the fixed stars in general increase in the direction of the Milky-Way and in it. This is more evident when we use a telescope, for the telescopic stars greatly out-number the others.

FIG. 97.



Star-Clusters. 1. In Libra. 2. In Hercules. 3. In Capricornus. 4. In Serpens. 5. In Aquarius. 6. In Gemini.

232. Nebulæ.—A nebula looks like a patch of cloudy light. There are two classes of nebulæ; those whose light is shown to be due to a great collection of telescopic stars, and those which no power of the telescope yet

FIG. 98.

Planetary Nebula in Ursa Major.

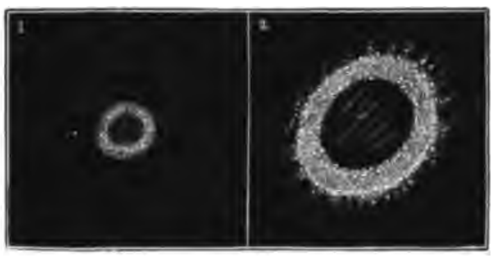
FIG. 99.

Elliptical Nebula near γ Andromedæ.

used by us has resolved into stars. Of the latter, many have been shown by the spectroscope to be masses of glowing gas.

There is a remarkable nebula in the sword-handle of Orion. It can be seen by the naked eye surrounding the middle of the three stars in the handle. It was examined by Professors Secchi and Huggins with the spectroscope, and they found lines leading them to believe it composed of glowing gas. Another remarkable nebula which can be seen with the naked eye is the great nebula of Andromeda. The triangle in Cancer contains a nebula which can be seen without the telescope. It is called Præsepe, or the Bee-hive Nebula. Great numbers of nebulæ are seen with the telescope, but they are most numerous at a distance from the Milky-Way. Some, as seen in Fig. 98, are round in appearance like a planet, and are therefore called Planetary Nebulæ. Other nebulæ are elliptical (Fig. 99), while still others are ring-shaped (Fig. 100). Some are oval (Fig. 101). Some consist of a hazy circle surrounding a star, which is therefore called a nebulous star (Fig. 102). Besides these, there are nebulæ of many irregular shapes (Fig. 103). Some are spiral, and look as if they might be in rotation around some central point. (See Figs. 104 and 105.) Fig. 106 is a representation of the nebula of Orion.

FIG. 100.



Ring-Nebula in Lyra.

FIG. 101.

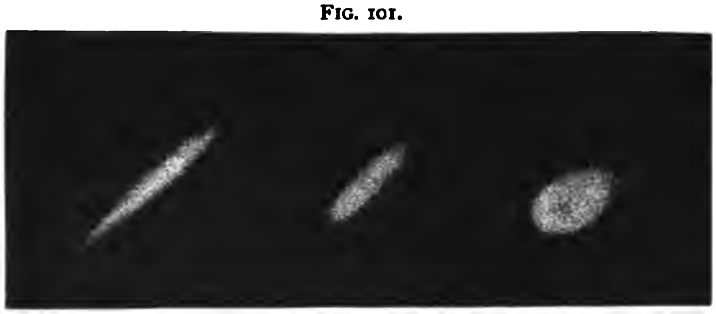
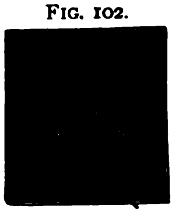


FIG. 102.



Nebulous Star, ι Orionis.

FIG. 103.

Crab Nebula in Taurus.

FIG. 104.

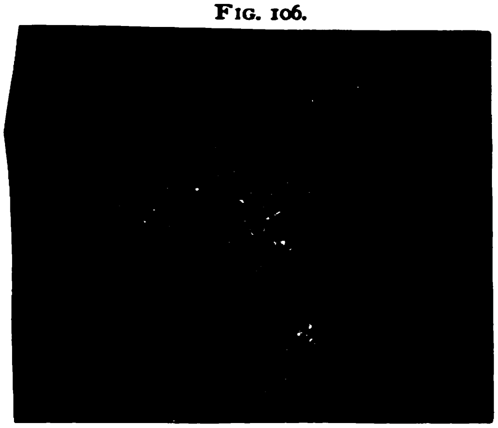
233. The Magellanic Clouds.—Travelers in the southern hemisphere of the earth long ago brought accounts of two large masses of cloudy light which they saw near the south pole of the heavens. They are

FIG. 105.

Spiral Nebula in Canes Venatici.

called the Magellanic Clouds, and they are further distinguished from each other as Nubecula Major and Nubecula Minor.

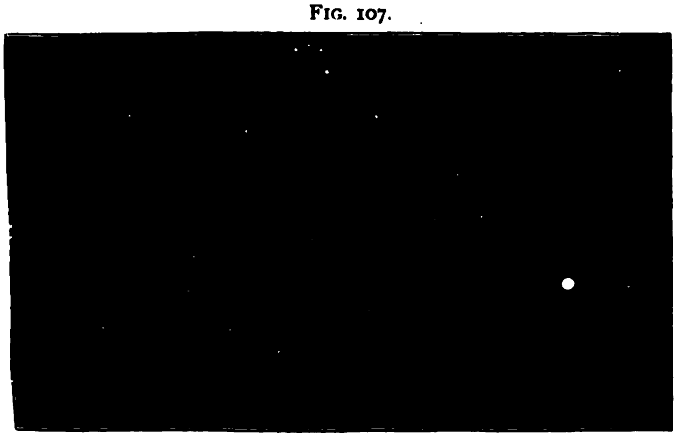
FIG. 106.



Great Nebula of Orion.

Nubecula Major is of course the larger, and it is so bright that it is not obscured by the full moon, which causes Nubecula Minor to become invisible. When seen through a powerful telescope, they are both resolved into stars and separate nebulæ. Of the latter, Herschel counted 278, besides more than fifty outlying nebulæ. (See Fig. 107.)

FIG. 107.



Part of the Nubecula Major.

234. The Nebular Theory.—A great many astronomers believe that suns and planets are formed from nebulæ.* The nebulous matter is supposed to be very hot and rotating rapidly. It gradually condenses and flattens into a rotating disk. This throws off rings which revolve and finally condense into planets, the central and large mass constituting a sun. The facts which they adduce in support of this theory are: the evidences of the earth's former fused condition; the flattening at the poles seen both in earth and planets; the fact that planets and moons (with two exceptions) all revolve from west to east, or in the same direction with each other; the rings of Saturn; the partially fused and vaporous condition of the larger planets, which would cool more slowly; and the spiral form common among the nebulæ.

The opponents of this theory consider the fact that the moons of Uranus and Neptune revolve from east to west a serious objection to it, and also the fact that one of the moons of Mars revolves around Mars, in a shorter time than Mars revolves on his axis.

235. Southern Circumpolar Constellations.—To people in the United States, these are in the Circle of Perpetual Disparition, so that the student can not see them in nature, but he should know something of them. An account of them is placed here, because they may be overlooked in the Description of Constellations in the Appendix, which is intended for reference only.

The chief groups are: Ara, *the Altar;* Crux, *the Cross;* Dorado, *the Sword-Fish;* Hydrus, *the Water-Snake;* Pavo, *the Peacock;* the Southern Triangle, and Toucanus, *the Toucan.* Three, viz.: Phœnix; Grus, *the Crane;* and Centaurus, *the Centaur,* can be partially seen in the Southern States, but the two first-magnitude stars in Centaurus are not seen in the United States at all. The Southern Cross contains one first-, three second-magnitude stars. It is the glory of the Southern skies. There are six first-magnitude stars around the southern pole. One of these, Canopus, can be seen in Tennessee. It presents a fine appearance in Georgia, and in the clear skies of Florida it is an object of much interest to visitors acquainted with astronomy. It is south of Sirius.

NOTE.—In the summer of 1885, a new star appeared in the nebula of Andromeda. It could not be seen except with the telescope. It increased in luster from its appearance in August until September, when it had attained the size of a star of 7½ magnitude. It then began to decrease, and by September 20th was of the 9th magnitude. This phenomenon is supposed to be due to some sudden evolution of burning gas in a star previously too small to be seen even with the most powerful telescope.

* Many of those who believe this theory also believe in a Creator, and in the Christian religion.

APPENDIX A.

DESCRIPTION OF CONSTELLATIONS.

ALPHABETICALLY ARRANGED.

(These are intended merely for reference, to aid students in learning the constellations from nature.)

ABBREVIATIONS.
- I.—1st m., 2d m., etc., are applied to stars, to designate first magnitude, second magnitude, etc.
- II.—E., W., N., S., N. E., S. E., N. W., S. W., are used to designate the various points of the compass.
- III.—Z. C. These letters are affixed to all Constellations of the Zodiac.

ANDROMEDA. This constellation is best learned after Pegasus. The N. E. star in the figure called the Great Square of Pegasus, belongs to Andromeda. This and two other 2d m. stars extend N. E. from Pegasus, in a line not quite straight. There are, also, two 3d m. stars on the map. The Great Nebula of Andromeda is one of the most remarkable in the heavens.

ARIES. Z. C. Aries is best learned after Andromeda, Pisces, or Taurus. There is a small irregular triangle, containing one 2d m., two 3d m. stars. This must not be confused with another triangle, which is the constellation Triangula. Triangula is a slender, nearly isosceles triangle, which contains no 2d m. star. Both are S. E. from Andromeda. All other stars of Aries, except the three in the triangle, are very faint. The ecliptic runs a little more than 8° south of the triangle, which, therefore, is not in the Zodiac, though part of the constellation is there. No star visible to the unaided eye marks the ecliptic.

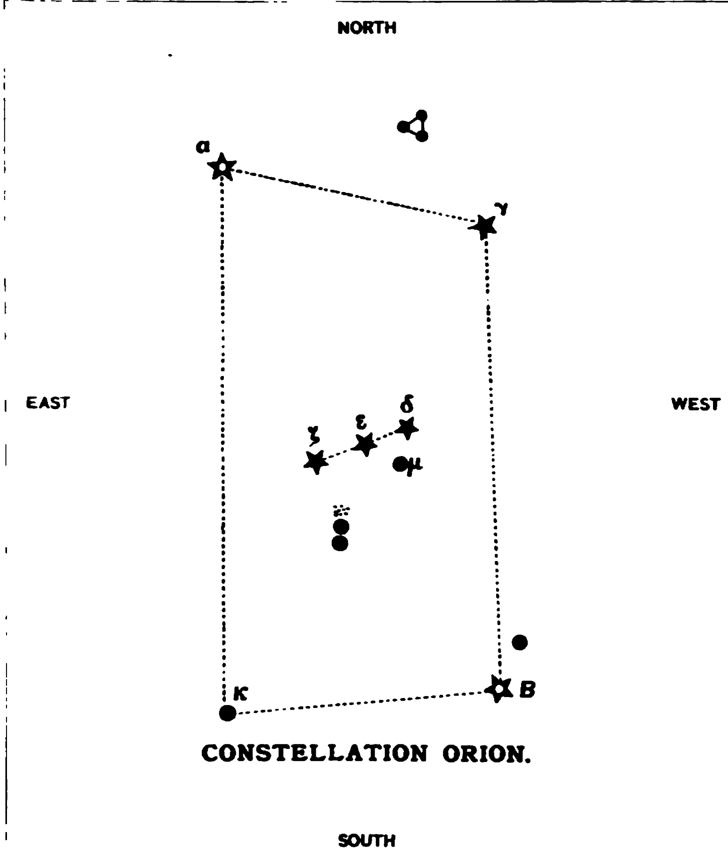
AQUARIUS. Z. C. The Water-Bearer. Also, Fomalhaut of Piscis Australis. Aquarius contains a small Y, formed of 4th m. stars, which is quite distinct and easy to find, since it is not far S. W. from the Great Square of Pegasus. There is also a figure which, in shape, resembles somewhat the continent of South America. S. A. has 3d m. stars at the angles, but the others are faint. There is risk of getting students to call it South America, by which name it is of course not known to astronomers; but when attention is called to the resemblance, it makes the constellation much easier to find. A line from the little Y, through S. A., reaches the 1st m. star, Fomalhaut, in the eye of the Southern Fish. Fomalhaut is farther south than any other 1st m. star except Canopus, which is not seen north of Tennessee. To the east of S. A. there are a number of small stars in little clusters of twos and threes. Aquarius is a man pouring water from a cup. The little Y is on the cup, and the water is pouring from it. The little clusters of twos and threes are in the stream, and so are Fomalhaut and the Fish. The ecliptic crosses S. A., and east of S. A. are two 4th m. stars joined together by a line on the map, which mark its course. The two southwest stars in S. A. belong to the constellation Capricornus. This should be impressed upon students after they find S. A. It is almost impossible to have Aquarius learned without using the distinguishable figure S. A., and with care there will be no confusion. The author has taught Aquarius to many children aged twelve, and always without going out with them at night.

AQUILA, or the Eagle. Aquila is easily distinguished by three stars in a short line, lying nearly across the Milky-Way. One is the 1st m. star Altair. Aquila comes in summer, when the brightest part of the Milky-Way is visible. The figure of A. on the map contains 3d M. stars, and is easily recognized. It lies in the Milky-Way,' nearly overhead when on the meridian. One of the stars, Eta, is on the equinoctial. A. can be learned by its position in the Milky-Way, without knowing any adjacent constellation ; or A. may be learned after Sagittarius. Altair can also be known by being the brightest star of the Milky-Way as seen in summer.

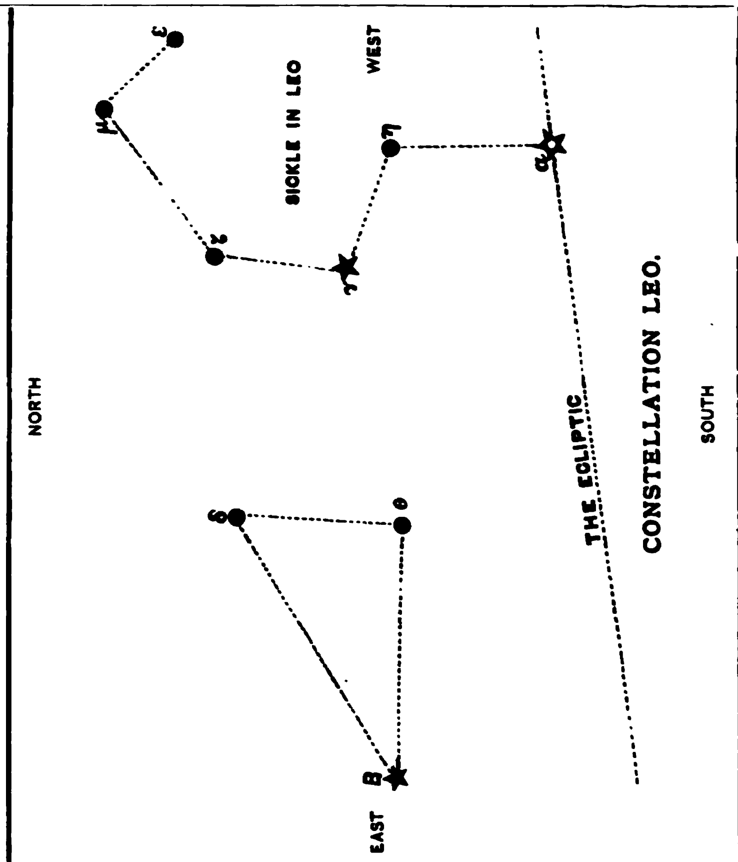
AURIGA, or the Wagoner. This can be learned after Orion, Perseus, or Gemini. It is very conspicuous, and easily found. It is an irregular five-sided figure, containing one 1st m. star, Capella, and two 2d m. stars. There is a small, slender triangle, called "The Kids," which is easy to find.

ARGO NAVIS. The Ship Argo. This may be learned after Canis Major, from which it is S. E. There are a number of bright stars on the southern horizon, but they are not combined into any figure on the map. They are easily found. One 2d m. star, Naos, is clearly seen; and in the Southern States, another 2d m. can be recognized on clear nights.

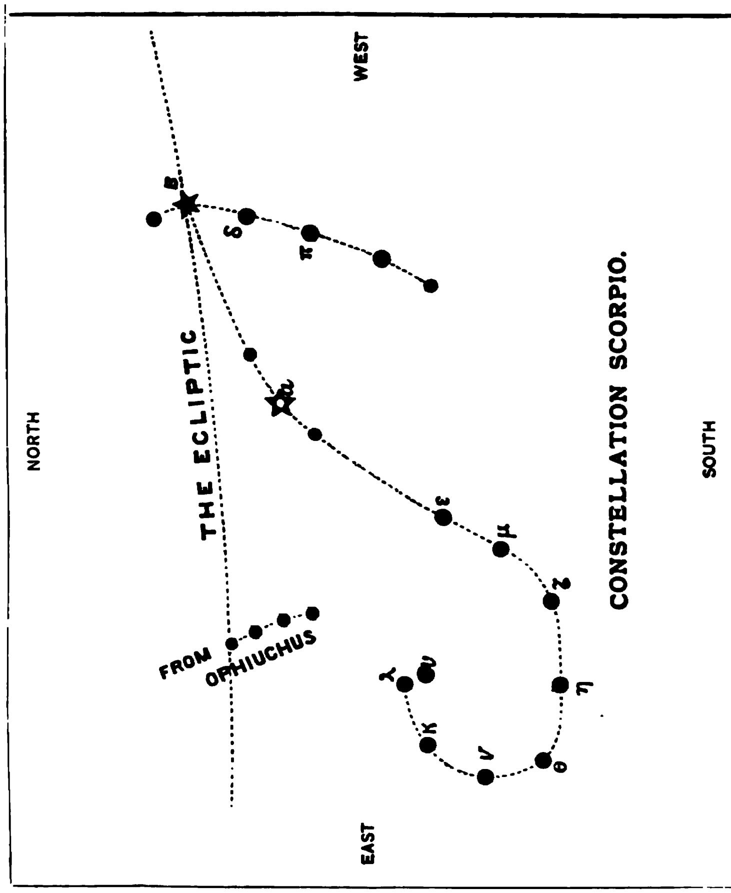
BOÖTES. Boötes can be easily found after the Great Dipper is known, from which it is S. E. In early spring, when the Great Dipper is in the east, a brilliant 1st m. star can be seen in the northeast, long before the whole constellation Boötes can be found. This star is



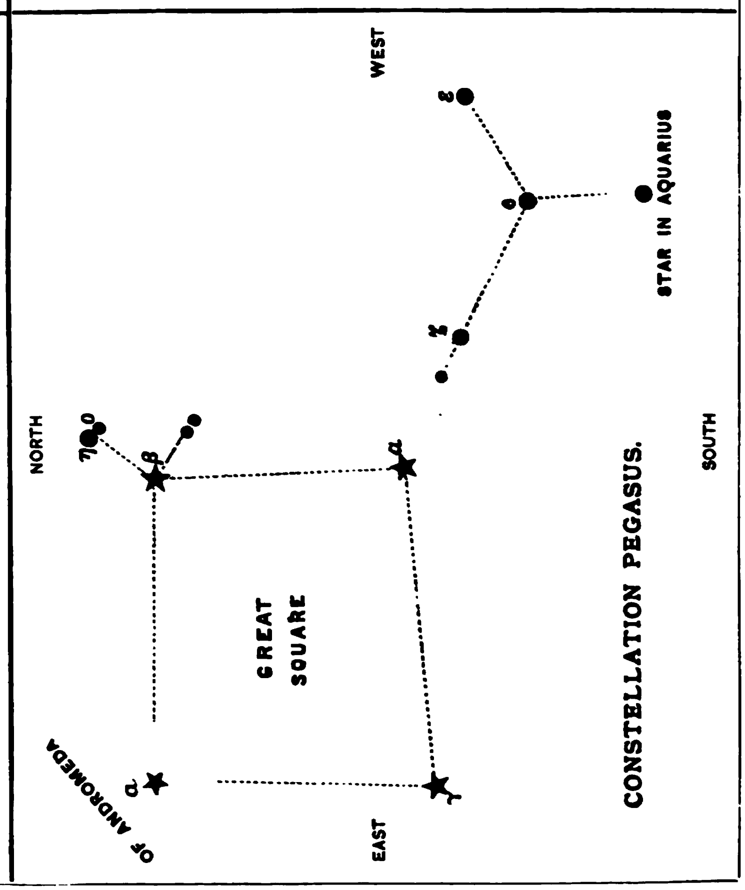
CONSTELLATION ORION.



CONSTELLATION LEO.



CONSTELLATION SCORPIO.



CONSTELLATION PEGASUS.

Arcturus, and in looking for Boötes it is best to find Arcturus first. Three stars are in line with Arcturus, and two of these, with others, form a figure resembling a kite. There is also a small triangle S. W. of A., with one 3d m. star. Also, S. E. from A., there are three stars nearly in line, of which one is 3d m.

CANCER. Z. C. Cancer is a very inconspicuous constellation, but not at all difficult to find after Gemini or Leo are well known. It is between them, a little S. E. from Gemini, a little N. E. from the Sickle in Leo. There is a small triangle of 4th and 5th m. stars, made more evident by having in its center a patch of cloudy light, which is Præsepe, or the Bee-hive nebula. In the telescope, it is a cluster of stars. The triangle is important, because one of the most southern stars is on the ecliptic.

CANIS MAJOR. The Greater Dog, sometimes called Sirius, from the name of its 1st m. star Sirius, which is the brightest of all the fixed stars. Sirius is sometimes called the "dog-star," and the dog-days of summer owe their name to the fact that Sirius is on the meridian above us at noon, during the dog-days. Of course, we can not see him there, but his position is known by calculation. The Greater Dog is best learned after Orion, from which it is S. E. After drawing, there is no possible chance to mistake it.

When Sirius is south of us, there can be seen in Florida, and States in the latitude of Georgia, a fine 1st m. star, Canopus, just above the southern horizon. It is so far south that it makes but a small arc in crossing the sky, and is above the horizon but a few hours. As it is so near the horizon, it is liable to be blotted out by smoke or fog except on very clear evenings. But the observer in the States mentioned should look for it. It can be seen in the latitude of Tennessee by a person familiar with it; but it is very near the horizon, and its luster is somewhat obscured.

CANIS MINOR. The Lesser Dog. This can best be learned after Gemini, Orion, or Leo. It is S. or a little S. E. from Gemini, nearly E. from the northern part of Orion, and S. W. from Leo. There are two stars on the map; one a 1st m. star, Procyon, the other 3d m. Procyon and the 3d m. star are about as far from each other as Castor and Pollux, and, if they were more nearly equal in magnitude, would look a good deal like Castor and Pollux.

CANES VENATICI. The Hunting Dogs. These form a very inconspicuous constellation between the Great Dipper and Boötes, and contain only a single 3d m. star midway between the two, which is not at all difficult to find. They are put in this "Description" because the constellation shows in the telescope a very remarkable spiral nebula, mentioned in another part of this book.

CAPRICORNUS. Z. C. This is best learned after Sagittarius or Aquarius. There are two 3d m. stars near each other, and forming a short line nearly at right angles with the line of the ecliptic. It is midway between Sagittarius and Aquarius, and is easily found. The ecliptic is a little farther from the most southern star than they are from each other. In the figure in Aquarius resembling South America, the two 3d m. stars in the S. W. angle belong to Capricornus.

CASSIOPEIA. Cassiopeia is best learned after the two Dippers. If a line is drawn connecting the stars in the handle-ends of the two Dippers, and it is prolonged on the side of Polaris, it will pass through part of the figure of Cassiopeia, given on our map. In late summer and early autumn Cassiopeia is to the right of the northern sky at dark; in late autumn and early winter she is on or near the meridian at dark; in late winter and early spring she is to the left of the northern sky at dark. The figure made by the bright stars and one faint one resembles a chair, and is often called Cassiopeia's Chair. The faint star is in the front of the seat of the chair. Without this star, the figure of Cassiopeia somewhat resembles a very irregular W.

CENTAURUS. The Centaur. Centaurus is only partially seen in the United States, and is on the southern horizon, S. W. of Scorpio. Its most brilliant stars (1st m.) are below the horizon in the U. S. There are, however, some fine 3d m. stars. There is a figure of a large Y; a very small and not bright triangle above it; a slender, nearly isosceles triangle east of the Y; and, to the west of the other figures, two stars near the horizon. Centaurus is visible in the late spring.

CEPHEUS. Cepheus is an inconspicuous constellation near the pole. The figure resembles an irregular K. It lies between Cassiopeia, the head of Draco, and the Little Dipper, and is best learned in summer, late spring, or early autumn. It is N. of the Cross in Cygnus.

CETUS, or the Whale. This constellation is best learned after Pegasus, Aquarius, and Pisces. It consists, as can be seen on the map, of a quadrilateral of 3d m. stars, E. of Aquarius, and easily distinguished. One of the stars of the quadrilateral has another near it. N. E. from this quadrilateral there is a triangle containing a 2d m. star. On the map, the triangle and the quadrilateral are joined, forming a figure resembling the mantis insect, popularly called the "*devil-horse*." E. of the quadrilateral, and between it and Aquarius, are two stars, one 2d m., one 3d m., joined on the map by dotted lines. E. of the quadrilateral there is a small square composed of 3d and 4th m. stars, from which a chain or stream of stars runs south, forming part of the constellation Eridanus. Cetus contains the remarkable variable star Mira, but it is half the time invisible. It forms a triangle with the N. E. star of the quadrilateral and the N. W. star of the small square.

COLUMBA, or the Dove. S. of Lepus and Orion there is a small cluster of stars containing one 2d m. and one 3d m. star. This is Columba. The 2d m. star is called Phaet.

COMA BERENICES. Berenice's Hair. This is a large cluster of very small stars which can best be learned after Boötes or Virgo. It lies N. from

Virgo, and W. from Boötes. It lies directly S. from the Great Dipper, but can be seen only when the Dipper is above the pole.

CORVUS. The Crow. The Crow is standing on the Water-Serpent, Hydra, and is best learned with it. It is an irregular quadrilateral, and the star at two of the angles has another near it. It is very easily distinguished, and is just S. of Virgo. The solstitial colure passes near it.

CORONA BOREALIS. The Northern Crown. This constellation is best learned after Boötes, from which it is E.; or Ophiuchus, from which it is W. It is easily distinguished by a figure resembling a semicircle, and by the 2d m. star Gemma.

CYGNUS, or the Swan. Cygnus is visible in summer and autumn, and is easily found, because it is in the part of the Milky-Way then visible. It may also be learned after Pegasus, Hercules, or Aquila. It is in the part of the Milky-Way N. E. from Aquila. The figure of a cross is so evident that it is easily identified. The upper or northern part of the cross is composed of bright stars, and the arms are in a line across the Milky-Way. The star at top of the cross, Deneb, is a very bright 2d m. star. The upper part of the cross should be found first.

DELPHINUS, or the Dolphin. Delphinus may be learned after Cygnus, from which it is S. E.; or after Aquila, from which it is N. E.; or after Pegasus, from which it is nearly W. It is easily distinguished in summer and autumn, because it is very near the middle point of the part of the Milky-Way then above the horizon, and on its eastern side. It consists of a small diamond-shaped figure, with another star. All except one of these stars are 3d m. The diamond or lozenge figure is popularly called Job's Coffin.

DRACO, or the Dragon. Draco can best be learned in late spring, summer, or early autumn. It should be learned after the student knows the Dippers and the 1st m. star Vega in Lyra. The two Dippers should be drawn first, and Draco added afterward. In looking for it, the student should be directed to look first for the head. A straight line from Vega to the bowl of the Little Dipper passes through the head of Draco. It is a very small, irregular quadrilateral, containing two 2d m. stars which can not fail to be recognized. The two other stars of the quadrilateral are fainter. One is 3d m., one 4th m. After finding the head, the student must look for the tail. A chain of stars forming it surrounds the Little Dipper, passing between it and the Great Dipper; and, after making more than half the circuit, it makes a turn back to join the head. One of these stars is of interest, because the pole of the heavens was once very near it. It is called α of Draco, and it lies in a straight line between ζ, a star in the bend of the handle of the Great Dipper, and γ, one of the two stars called "Guardians of the Pole," which lies in the bottom of the bowl of the Little Dipper.

ERIDANUS, or the River Po. This constellation lies between Cetus and Orion. There are two irregular chains of stars, of which one extends from the triangle in Cetus to Rigel in Orion (a 1st m. star). It contains a 2d m. star. The other chain runs from the little square in Cetus to the southern horizon.

GEMINI, Z. C., or the Twins. This is best learned after Orion or Leo. The two brightest stars are called Castor and Pollux. Pollux is called 1st m., Castor 2d m., but it takes close observation to see any difference. There are three stars in Gemini lying nearly on the ecliptic, and one of these, the extreme western star of the map, is a little E. of the point where the sun is situated on June 22d. The point is called the Summer Solstice. The student should mark this point S. S., in drawing the constellation.

HERCULES. Hercules is best learned after Boötes Ophiuchus, or Draco. After drawing Hercules and Ophiuchus separately, and finding them, they should be drawn together, because the figures run together. Hercules contains no stars brighter than 3d m. The solstitial colure runs just E. of Hercules.

HYDRA. The Water-Snake. Hydra is best found in April or May, after Virgo, Leo, Cancer, and Libra are known, for it lies S. of them all. It is a long constellation, extending N. W. and S. E. It is best to find the head first. That lies just S. of Cancer, and, though composed only of 4th and 5th m. stars, is perfectly distinct and easily found. It looks a good deal like the nodding bud of a fuchsia-blossom. After learning the head, the student will do well to find the 2d m. star, Al Fard, or Cor Hydra, which is S. of Leo. Then he finds Corvus, a separate constellation (see CORVUS), S. of Virgo, but one which should be drawn with Hydra. W. of Corvus, three 3d m. stars extend in an almost E.-W. line toward Libra. Between Corvus and Cor Hydra there are a good many very small stars, but it is not important to distinguish them; and it is well to let the student represent them in his drawing by a few flourishes. Part of them constitute a separate constellation, called Crater, or the Cup, which is on Hydra; but it is unimportant. The triangle N. E. of Cor Hydra should be found. The equinoctial crosses this constellation north of this triangle and Cor Hydra.

LEO MAJOR.* Z. C. The Greater Lion. Leo can be found in spring without knowing any other constellation than the Great Dipper, from which it is S. W. The fine 1st m. star Regulus will be easily recognized. It is not very near the Dipper, but no other 1st m. star comes between the two. Regulus is in the handle-end of the Sickle, which the student is supposed to have drawn when he looks for Regulus. There is another figure, a right triangle, belonging to Leo, lying W. of the Sickle, and containing a 2d m. star, Denebola. Regulus is nearly on the ecliptic, the only 1st m. star which marks it. Leo can, of course, be easily learned after Cancer, Gemini, or Virgo, if they are already found. It is between Cancer and Virgo, between Gemini and Virgo. (See page 81.)

LEO MINOR. The Lesser Lion. This is a very inconspicuous constellation. One 3d m. star

* This constellation is usually called simply Leo.

can be found by the student between Leo Major and the Great Dipper. This is the only bright star in Leo Minor.

LEPUS. The Hare. This can be found after Orion, from which it lies directly S. There are two figures on the map. Nearest Orion there is a row of three stars; and S. of that, an irregular figure like a woman's hanging sleeve.

LIBRA, Z. C., or the Balances. This can be found after Virgo or Scorpio, as it lies between them. There is a somewhat irregular quadrilateral with two 2d m. stars; the others are 4th m. The ecliptic passes nearly through the most southern of the 2d m. stars, and between the two 4th m. One of the two 2d m. stars marking the ecliptic is in Libra; the other is in Scorpio.

LYRA. The Harp. In late spring a fine 1st m. star of a bluish appearance is seen in the N. E. This is Vega in Lyra. Lyra can be found after Hercules or Cygnus. It is E. of Hercules, W. of Cygnus, and lies not far from the western border of the Milky-Way. Two 4th m. stars very near it form a very small, nearly isosceles, triangle. One of these, which young eyes can see is double, is ϵ Lyræ, the double star mentioned in the last chapter of this book. There are two 3d m. stars a little farther off. The constellation is very small.

MUSCA. The Fly. This is a very small group containing one 3d m. star. It lies S. of Algol, in Perseus; S. E. from Triangula; N. E. from Aries.

NAVIS. See Argo.

OPHIUCHUS, or Serpentarius. The Serpent-Bearer. This is usually divided into two constellations, viz., Ophiuchus and Serpens. They are here treated as one. Ophiuchus is best learned after Hercules, or Boötes and Corona, Aquila or Scorpio. It is a very large constellation, and contains four 2d m. stars. It is just W. of the Milky-Way, which aids to find it. The most western stars run between the divided part of the Milky-Way. Hercules and Ophiuchus run so into each other that it is difficult to separate them into two figures; and, after drawing each separately, they should be drawn on the same paper.

ORION. This is the most brilliant constellation in the heavens. It can be found after knowing Gemini, Sirius, or Taurus; or it can easily be found, without any other guide than its own conspicuous figure, as soon as the student can draw it from memory. In the early winter it is seen in the E. at dark; it passes the meridian at dark about the close of February and the beginning of March; and after that it is seen in the W. until late in spring. When it passes the meridian, it must be looked for a good deal S. of the observer. There are two 1st m. stars, Rigel and Betelguese. Betelguese is farther N. than Rigel, and reddish. Another of the four stars forming the quadrilateral is 2d m. This is called Bellatrix. Within the quadrilateral are found three 2d m. stars in a line running S. E. and N. W. They are said to be in the belt of Orion. There runs a line of stars S. from these which are said to be in the sword-handle. One of these looks hazy. It is the nebulous star mentioned in Chapter XI. The small triangle which lies in the N. of the quadrilateral is said to be in the neck of Orion. (See page 81.)

PEGASUS. Pegasus can be learned after Aquarius, Cygnus, or Andromeda; or it can easily be recognized by its own conspicuous figure, if the observer has drawn it. Four 2d m. stars form a large square, not exactly regular, called the Great Square of Pegasus; and to the N. W. angle is attached a triangle of smaller stars, which aids in identifying it. The N. E. star of the Great Square really belongs to Andromeda, but helps to complete the Great Square. In September Pegasus is seen in the E. at dark; it passes the meridian at dark in early winter, when it is nearly overhead; and after that it is seen in the W. at dark until March. S. W. from the Square there is another figure which the student must learn by drawing it, after he knows the Square. (See page 81.)

PERSEUS and Medusa's Head. This is very easily learned after Cassiopeia, Auriga, or Taurus. It lies in the Milky-Way. Part of Perseus is a portion of a circle called the Segment of Perseus. Its concave side turns N. E. Besides this a curved branch runs S. W., and, at the end of the branch, two stars make a sudden bend. E. of this curve there are two stars, one a not very bright 2d m. The two are near each other, and the 2d m. star is the remarkable variable star Algol, or Beta Persei. An account of it is given in Chapter XI. There is a 2d m. star in the Segment of Perseus called Algenib. It is at the junction of the segment and branch.

PISCES. Z. C. The Fishes. This constellation is best learned after Pegasus, Aquarius, and Andromeda. Only one star is as bright as 3d m.; but, with a little care, the constellation is easily found, as it is not indistinct. The student must find first a small hexagon, not quite regular, of 4th and 5th m. stars, not indistinct. From the hexagon a chain of faint stars runs nearly E. and W., terminating in a 3d m. star. From this another chain runs nearly N., and just S. of Andromeda it meets a cluster of faint stars. This last cluster is the Northern Fish, or Piscis Borealis. The hexagon is the Western Fish, or Piscis Occidentalis. The two most southern stars of the hexagon are nearly on the equinoctial, and a very little E. of them is the point where the sun is found at the Vernal Equinox on March 21st. If a line were drawn S. through the two eastern stars of the Square, it would be a little E. of the Vernal Equinox. On the maps of Pisces made by students, the point should be marked V. E. There are three 4th m. stars in the chain running E. from the Western Fish. The ecliptic runs just S. of them, and crosses the chain or ribbon, as it is sometimes called, just W. of them. The chain connected with the Northern Fish has in it one 4th m. star, and farther S. two 5th m. stars. Between the two 5th m. stars the ecliptic crosses that chain. The 3d m. star joining the chains is a very little N. of the equinoctial.

PISCIS AUSTRALIS. The Southern Fish. This has already been described in Aquarius.

SAGITTARIUS. Z. C. The Archer. This constellation is seen in summer and autumn, and, when Scorpio is known, it can be found from it; but it is also very easily distinguished, because it is at the southern and brightest part of the Milky-Way. First a small figure must be found, like a dipper turned upside down. This is called the "Milk-Dipper." S. W. of this, and just in the Milky-Way, is a small right triangle containing a 2d m. star. N. E. from the Dipper there is an irregular cluster of very small stars, not bright, but important, because the ecliptic passes through them. Nearly N. from the right triangle is the point where the sun is found on December 22d, at the winter solstice. The point should be marked on the maps of students.

SCORPIO. Z. C. The Scorpion. This constellation can be found in the S. on any clear summer evening, first by the brilliant 1st m. star Antares; and next by its peculiar shape, outlined by many 3d m. stars. Antares is very red, and nearer the southern horizon than any 1st m. star seen in summer, so there is no possible chance to mistake it. There is also a 2d m. star, and the ecliptic passes nearly through it. This is one of two 2d m. stars which mark the course of the ecliptic. The other is in Libra, just W. of Scorpio. If the student knows Libra, Sagittarius, or Ophiuchus, Scorpio can be learned from them. Scorpio is E. of Libra, W. of Sagittarius, S. of Ophiuchus. After drawing, it is impossible not to recognize it, though it is so near the horizon that the tail is often a little obscured through smoke. N. of the tail there are four small stars in line, and the most northern is nearly on the ecliptic. These stars really belong to the constellation Ophiuchus, but are mentioned here because they aid us in tracing the ecliptic. (See page 81.)

TAURUS. Z. C. The Bull. Taurus can be learned after Orion, Auriga, Gemini, or Aries. It is N. of Orion, W. or S. W. of Gemini, S. W. of Auriga, E. or N. E. of Aries. There is a cluster of small stars popularly known as the "Seven Stars." They are all small, but united they become conspicuous. These are the Pleiades. S. E. from the Pleiades there is a figure like the letter V containing a reddish 1st m. star, Aldebaran. The V is called the Hyades. If a line be supposed to join the Pleiades and the Hyades, a small group of four 5th m. stars in a line will be just E. of it. The most southern one of these is nearly on the ecliptic, which runs between the Pleiades and Hyades.

TRIANGULA. The Triangle. This can best be learned after Andromeda and Perseus. It is a slender, nearly isosceles, triangle, lying between Perseus, Andromeda, Pisces, and Aries. It must not be mistaken for the triangle in Aries, which contains a 2d m. star, and is nearly S. from it. The triangle in Aries is not isosceles.

URSA MAJOR. The Great Bear. The map gives two figures for Ursa Major, viz., the Great Dipper, and a row of stars in twos S. W. from the Dipper. The Dipper is sufficiently described in Chapter I. The names of the stars of the Dipper, given in order, beginning with the handle-end, are Benetnasch, Alcor, Alioth, Megres (joining bowl and handle), Phad, Merach (the last two in the bottom of the bowl), and Dubbhe. It is not desirable to try to make students learn these, unless they study for a long time. There will inevitably be confusion among so many names. The row of stars in the feet is not well seen except in spring and summer. It is not desirable to teach it when the Dipper is first learned. After the more important constellations are learned there can be a review, if there is time, and this figure can be learned. These stars are in the feet of the Great Bear.

URSA MINOR. The Lesser Bear. This contains but one important figure, the Little Dipper, and that is fully described in Chapter I. Polaris is 2d m.; the Guardians are 3d m.

VIRGO. Z. C. The Virgin. This can best be learned after Leo, Libra, or Boötes. It is nearly E. (a little S. E.) from Leo, nearly W. (a little N. W.) from Libra, and it is S. W. from Boötes. The 1st m. star Spica helps to identify it. After drawing, the figure is very easily identified. There is a figure resembling somewhat a chair turned back, only the seat of the chair projects too much. The stars of the figure are 3d m., except Spica and a faint 4th m., through which the ecliptic passes and gives it importance. There is another faint 5th m. star in Virgo (but not in this figure) through which the ecliptic passes. It is, on the map, between the figure and Libra. This star is said to be in the feet of the Virgin. The ecliptic passes just S. of three of the 3d m. stars, which therefore mark its course. The point where the ecliptic crosses the equinoctial is the point where the sun is found September 21st. This is therefore the point of the Autumnal Equinox, and it should be marked in all copies of this map of Virgo, A. E.

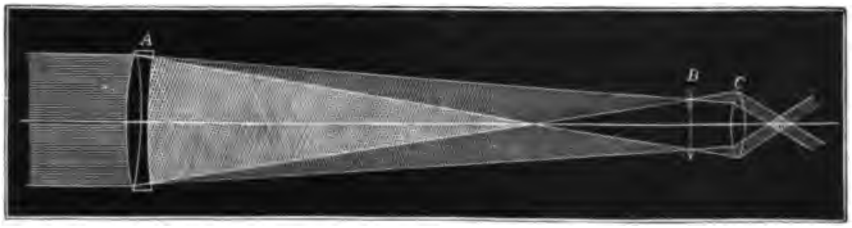
APPENDIX B.

THE TELESCOPE.

(*Taken chiefly from Lockyer's "Astronomy."*)

Construction.—The telescope is a combination of lenses. The principle involved in its construction is simply an extension

FIG. 108.



Construction of the Astronomical Telescope.

of that exhibited in the structure of the eye. In the eye nearly parallel rays fall on a lens, and this lens throws an image. In the telescope nearly parallel rays fall on a biconvex lens; this lens throws an image, and then another lens enables the eye to form an image of the image by rendering the rays again parallel. These parallel rays enter the eye just as they do in ordinary vision. In Fig. 108, for instance, let A represent the front lens, called the *object-glass*, because it is nearest to the object viewed; let C represent the other, called the eye-piece, because it is nearest the eye; and let B represent the image of a distant arrow, the rays from which are seen falling on the object-glass from the left. These rays are refracted, and we get an inverted image at the focus of the object-glass, which is also the focus of the eye-piece. The rays leave the eye-piece adapted for vision as they are when they fall on the object-glass; the eye can therefore use them as well as if no telescope had been there.

The efficiency of the telescope depends on two things—its illuminating power and its magnifying power. First, as to its illuminating power. The object-glass, being larger than the pupil of our eye, receives more rays than the pupil. If its surface be a thousand times greater than that of the pupil, for instance, it receives a thousand times more light; and, consequently, the image of a star formed at its focus is nearly a thousand times brighter than that thrown by the lens of our eye on the retina.

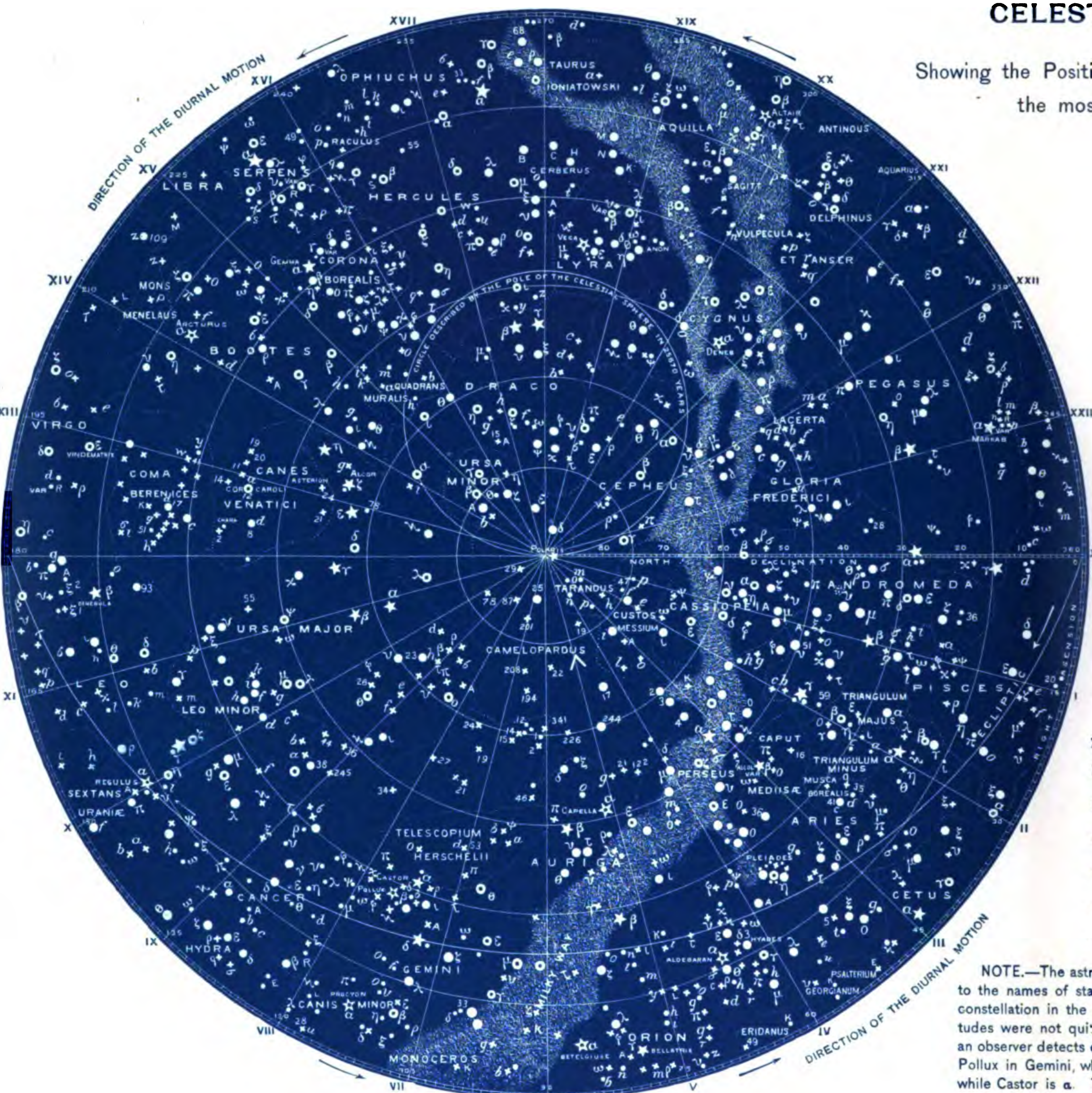
The magnifying power depends on two things: first, it depends on the focal length of the object-glass; next, the magnifying power of the eye-piece is to be taken into account. This varies according to the eye-piece used, the ratio of the focal length of the object-glass to the eye-piece giving its exact amount. Thus, if the focal length of the object-glass is one hundred inches and that of the eye-piece one inch, the telescope will magnify one hundred times. But, unless the illuminating power is good and a perfect image is formed, a high magnifying power is useless. If the object-glass does not perform its part properly, the image will be blurred.

The telescope-tube keeps the object-glass and the eye-piece in their proper positions; and the eye-piece is furnished with a draw-tube, which allows its distance from the object-glass to be varied.

Mountings.—An astronomer uses the telescope for different kinds of work. Accordingly, he mounts, or arranges, his instrument in several different ways. When he desires to watch the heavenly bodies, the only essential is that the instrument should be so arranged as to command every portion of the sky. The best mounting for this purpose is shown in Fig. 109. With such an instrument, called an equatorial, a heavenly body may be followed from its rising to its setting, the proper motion being communicated by machinery. In this arrangement there is a strong iron pillar supporting a head-piece, in which is fixed the polar axis of the instrument parallel to the axis of the earth. This polar axis is made to turn round once in twenty-four hours. The machinery turns the telescope in one direction just as fast as the heart moves in the other, and thus the instrument is kept all the times fixed on a heavenly body. It is inconvenient to fix the telescope on the polar axis, as its range is then limited; it is fixed, therefore, to an axis at right angles to the polar axis.

FIG. 109.

NORTHERN HEMISPHERE



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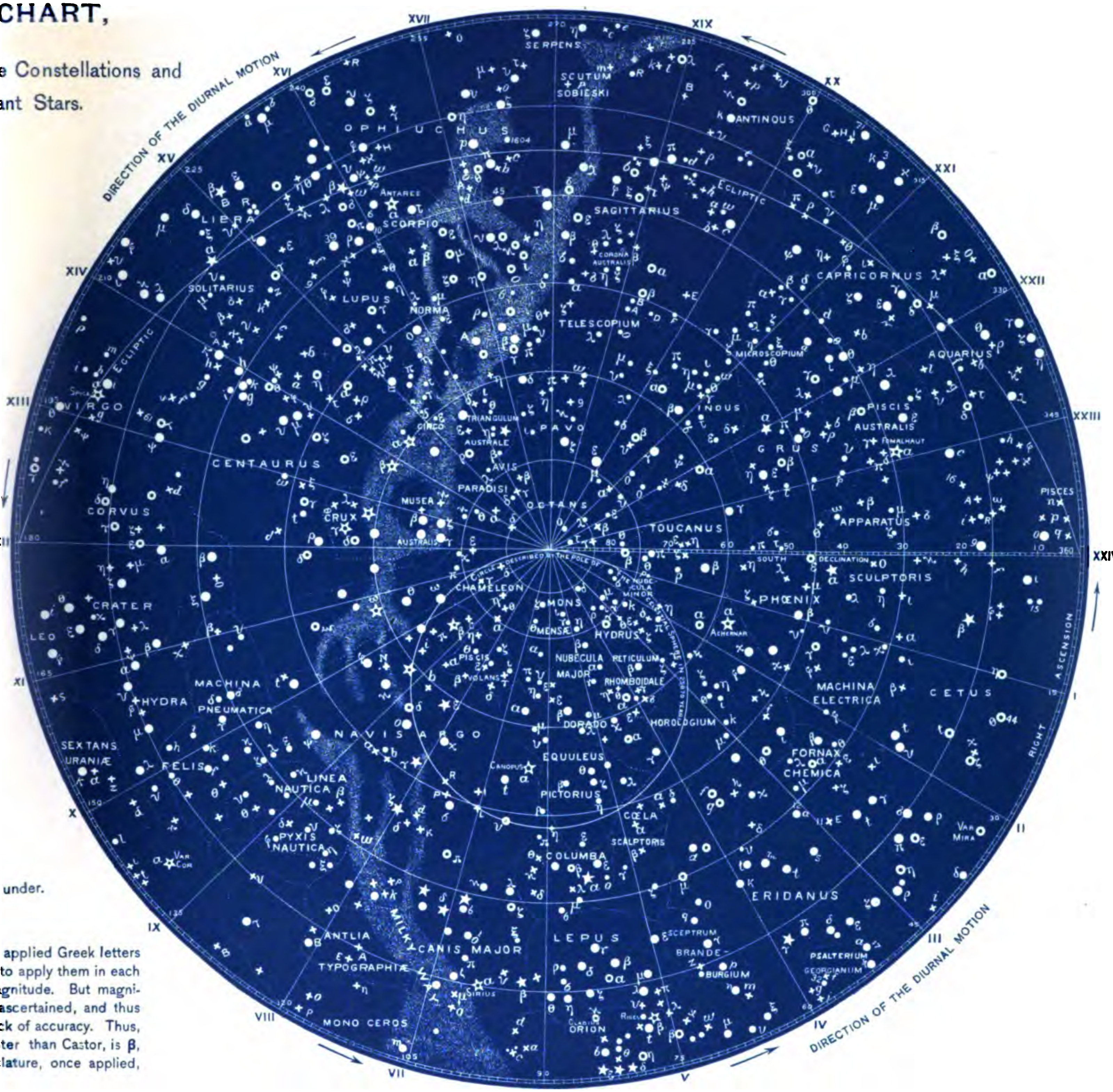
SOUTHERN HEMISPHERE



APPENDIX C.

OBSERVATION OF METEORS AND COMETS.

Mr. E. E. Barnard, of Vanderbilt Observatory, Nashville, Tennessee, a well-known observer of comets, gave to the author's pupils some simple directions for observation of meteors and comets, without instruments. They are of wider use, so the substance of them is here given.

Meteors.—On any evening when you see them, note carefully at what point among the stars each appears, at what point it disappears. Trace these paths, as you learn each, on a chart or globe of the heavens. If you are fortunate enough to see a number, you will find that some of the paths intersect. The point of intersection is the radiant, and you will have seen a shower. If you become an accurate observer, some of the periodicals devoted to the stars may be glad to publish your report. The record should be about as follows: 1st m. meteor, appeared $2\frac{1}{2}^\circ$ N., 3° W. of Vega; disappeared 4° due S. of Altair; time of flight, $1\frac{1}{2}$ second; color reddish, faint train, permanent for 5 seconds, exploded with several red sparks. To such a report is added the date, the mean time, and the exact location of the observer. Any change of color in the meteor during flight, or at the time of bursting, should be noticed and recorded. If the student chances to see a large meteor, there is a special value in his report, for the same object may be seen in some other place, and the two observations will enable astronomers interested in the study of meteors to tell all about it.

To this, the author adds a few words in regard to the observation of the Leonids, or November meteors. If the observer sees at once the trains of a number of meteors, the radiant point or intersection is evident without tracing on a map. On November 13th, the constellation Leo is on the eastern horizon at midnight, and the sun, of course, is on the meridian below the horizon. A line drawn from the observer to the sun, and another to the point where the ecliptic and eastern horizon intersect in Leo, would, it is evident, make a right angle. At midnight, the ellipse which is the earth's orbit is below us, except the point we are on (for the orbit must always lie on the same side of us as the sun). Thus it is plain that the line to the eastern horizon is a tangent to the earth's orbit.

Now, the student must remember that the earth's motion, like that of a key revolved by the hand on a string, would at any moment carry it in the direction of a tangent to its orbit but for the attraction at the sun holding it fast and continually bending the straight line into a curve or ellipse. Therefore, at midnight, November 13th, the earth is moving directly toward Leo, and the meteors are coming from the quarter toward which the earth is moving at that time. As we only see them on or near November 13th, it is evident that the paths of the earth and the meteors are not identical, but intersecting paths. As they come to meet us, their motion is retrograde, or from east to west. When the earth's rotation on her axis makes Leo appear to move west, the radiant point seems to move with it.

Comets.—In order to observe a comet with intelligence, the comet's position among the stars must be noted, and also the position of the sun at the time. Then it is easy for the observer to note its motion toward and from the sun, and the changes it undergoes in approaching and receding from him, especially the changes in its tail. Its path in regard to the ecliptic should be noted, as we thus gain some idea of the plane in which it moves. Mr. Barnard says, "In the case of a large comet, naked-eye observations may be worth recording. The time of the observation should be given to the nearest minute. The limits and general position of the tail should be carefully sketched, and that of the head, with notes as to curvature of tail, brightest parts, etc. Any markings on the tail, such as dark streaks, etc., should be carefully traced. Such work, done accurately, will be valuable work. Above all things, students should be taught to be very careful, and *have no uncertainties without fully stating them.*"

INDEX.

(The numbers refer to articles, not to pages.)

NOTE.—In making this index, the author designed that it should both answer the object of an index and serve as a list of topics for review. The order in which it is wise to treat a subject for beginners, necessarily separates subjects with some connections. It is nearly always best to review in a different order where it can conveniently be managed. It brings out relations which have been neglected, and excites the minds of students, to whom review is tiresome. The author, in teaching other books, has found a good index useful for review, and has employed this experience in making this index. Teachers who have never tried the plan of adopting a different order for review are recommended to make trial. Where the plan seems to make too much repetition, there may be omissions.

THE END.

CHAPTER IX.

THE PLANETS—GENERAL ACCOUNT.

186. The planets are arranged according to size in two classes, called respectively the Major and the Minor Planets.

187. The Major Planets are Mercury, Venus, the Earth, Mars, Jupiter, Saturn, Uranus, and Neptune. Mercury, Venus, Mars, Jupiter, and Saturn were all known to the ancients. Uranus was discovered by Sir William Herschel in 1781. It can be seen by the naked eye as a star of the sixth magnitude. It can, however, hardly be identified by any but an experienced observer who knows where to look for it, as its apparent size is so small and it moves so slowly. The discovery of Neptune has already been described.

188. The Minor Planets.—Besides the planets just named, there are a large number of small planetary bodies revolving round the sun between the orbits of Mars and Jupiter. They are called the Minor Planets, or Asteroids.

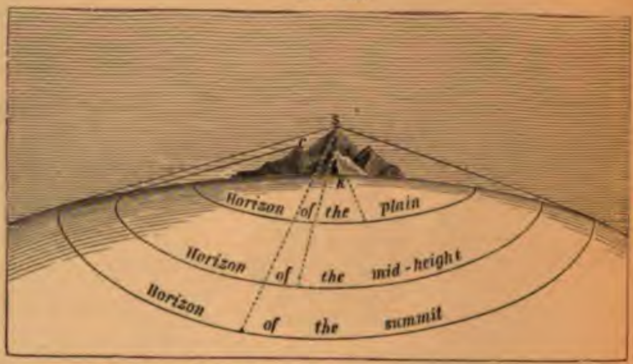
In the following list, the planets are named in the order of their distances from the sun, beginning with the one nearest the center: Mercury, Venus, the Earth, Mars, the Asteroids, Jupiter, Saturn, Uranus, Neptune. The distances from the sun increase with some regularity, and it was long noticed that there seemed to be a gap between Mars and Jupiter, so it was thought that some unknown planet might fill it. Early in the present century, four very small planets were discovered and called Juno, Ceres, Pallas, and Vesta. In 1843 another, called Astræa, became known; and since then more than two hundred have been found. New ones are often discovered. Many of them are very minute bodies.

Except Mercury and Venus, all the known planets are superior planets; that is, they revolve round the sun in orbits exterior to the earth's orbit. Their motions correspond to the motions of the superior planets described in Chapter VI. The angle through which their movement appears to retrograde, decreases as their distances from the sun increase.

In this book, the forms, volumes, densities, etc., of the planets are described together under these respective heads, because the student gains much more definite ideas by comparison.

189. Forms of the Planets.—The earth is one of the planets, and it will be best to speak of her figure first. The earth is round, or a sphere. We know this from a variety of facts: 1. The shadow of the earth, as seen on the moon when she is eclipsed, is always round. 2. The horizon is always a circle. If we are on a plain, our horizon is limited; if we ascend to a slight elevation, our view is more extended; and, if we go up a high mountain, we have still a wider horizon; but through all the changes our horizon is still a circle (see Fig. 64). This makes it quite certain that the earth is a sphere. 3.

FIG. 64.



Horizons of the Same Place, at Different Heights.

When vessels at sea come in view of an observer, we see first the top of the mast, then the upper sails; next the lower sails, and finally the hull. This is represented in Fig. 65, and shows conclusively that the surface of the ocean is spherical.

FIG. 65.

Proof of the Curvature of the Earth's Surface.

But the earth is not a perfect sphere. Her figure is flattened like an orange at the poles. Mathematicians describe the earth's figure as an "oblate spheroid." In order to understand some arguments made from these facts, the student is reminded of twirling a key, tied to